CARBWARE

Forest GHG Inventory Software: User Manual version1.5

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1. Introduction

CARBWARE is a forest carbon flow model, now made assessable as a standalone computer program. CARBWARE can be used to report GHG emission reductions or project these forward by simulating changes in forest carbon pools over a 15 year time span and over a "landscape" spatial scope (form 1 plot to 1000s of forest stands). The CARBWARE model simulates the flow of carbon within forests and between forests and the atmosphere (Figure 1). Carbon dynamics are simulated in aboveground, belowground biomass, litter, dead wood and soils pools. The removal of CO_2 from the atmosphere as a function of forest growth is simulated using models parameterised for different species cohorts, which exhibit similar growth characteristics (Spruce, Pines, Larch, other conifers, slow growing and fast growing hardwoods). It also includes mortality functions, decomposition factors for the deadwood and litter pools and soil emission factors, not normally captured by conventional inventory procedures. It also accounts for silvicultural management, such as those associated with thinning and clearfell. Although the current national GHG inventory assumes that all wood products (HWP) are immediately emitted to the atmosphere at harvest, the potential C storage in harvested wood products have not been included in the model. This is because HWP C modelling is best done at the national or regional scale (using industry data), but stand dynamics in the CARBWARE model is simulated in a bottom up basis (plot level up), using sample plot and conventional forest inventory information. Harvested wood products are simulated using another top-down model WOODCARB.

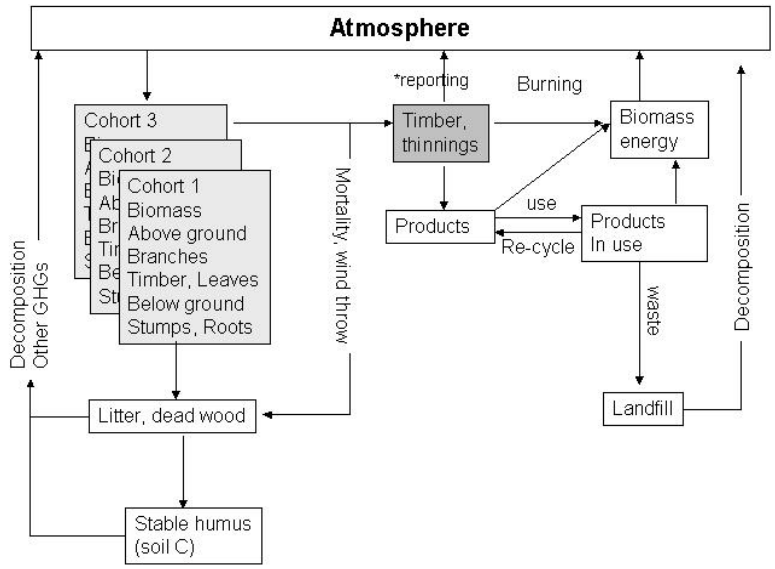


Figure 1. Flow diagram of proposed CARBWARE model including all components (for UNFCCC and Kyoto reporting, wood products are assumed to be a source at harvest).

The Irish carbon reporting system (CARBWARE), initially described by Gallagher et al. 2004, was implemented to meet reporting requirements to the UNFCCC on national forest sources and sinks. Since then, CARBWARE has evolved from a tier[1] 2 to tier 3 system, using forest inventory data, yield models and national research information (see Black and Farrell 2006, Gallagher et al 2004, Black et al., 2012, Duffy et al., 2011) to include activities relating to Articles 3.3 and 3.4 of the Kyoto protocol. Although the software was designed to meet Irish national forest reporting requirements under contract to the Irish Council for Forest Research and Development (COFORD), it can be used globally if input data are formatted in a compatible manner. However, it should be noted that the empirical tree growth and

[1] Tiers refer to methodological rankings used as set out by the IPCC good practice guidance. Tier 1 refers to default methods, higher tiers use country specific and more complex modelling approaches

mortality models have been developed using Irish permanent sample plot data (see Appendices). Users, outside the Ireland and the UK, wishing to extend the use of CARBWARE should consider developing eco-regional specific growth and mortality models and regional, species specific site factors, such as decomposition rates.

Tree growth and mortality is based on distance independent single tree growth models which use basic individual tree data such as DBH, Height and crown ratio and stand information such as stocking basal area and soil characteristics (Duffy et al., 2001; Hawkins et al., in press). The input data and archiving systems requirements are outlined in section 4. The functionality of the various components of the software (Growth simulator, stand modifier, CO_2 allocation and reporter are outlined in section 3). All intermediate and final output files from a set of projections (i.e. a project) are stored on Microsoft Access files (see system requirements section 2), which controlled by the user. The Output data is collated in a format compatible with the Common Reported Format (CRF) tables used in UNFCCC and Kyoto reporting of the LULUCF sector.

2. Getting Started

2.1 The Intended User

The software is designed for users interested in assessing stand level or regional carbon stock changes in forests for **Ireland and the UK**. It is assumed that the user has grounding in forest inventory and mensuration and a good understanding of database management, particularly using MS access. The software is very easy to run, but a good knowledge of your specific inventory procedure and measurements taken is required to compile input data base files. The primary target user for the current version of CARBWARE is the Irish national forest inventory (NFI) staff or national inventory compilers for reporting of forest emissions and removal to the UNFCCC.

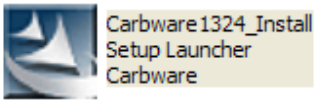
2.2 Hardware requirements

The software is designed to operate on all current Microsoft Windows operating system versions (XP, Vista and Windows 7) which have Microsoft Access installed. The minimum hard disk space requirements will depend on the size of the forest inventory databases used. For example, if the current NFI database is run for 15 years, the required hard disk space is approximately 100 MB.

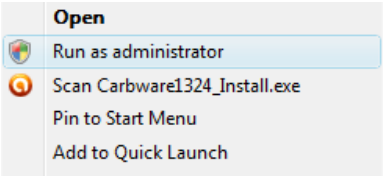
2.3 Installing Carbware on your PC

You will receive your version of Carbware on an installation CD.

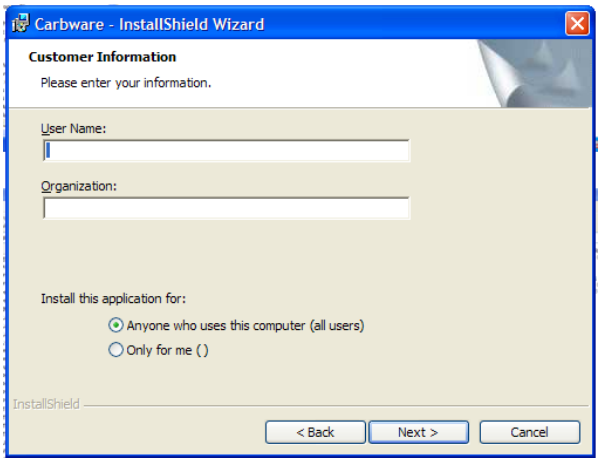
- Using Windows Explorer double click the Carbware Setup Launcher Icon:



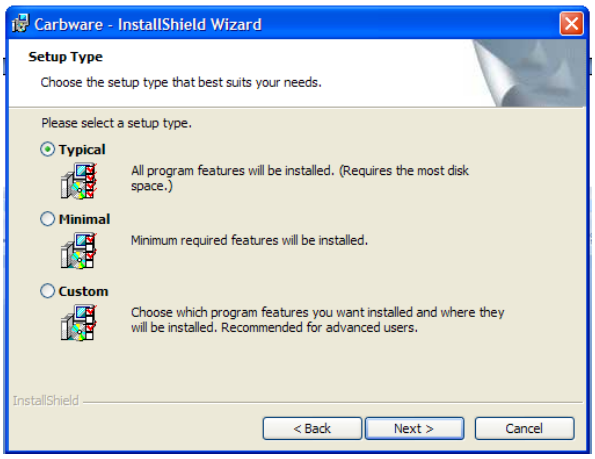
Important: For users with Microsoft Windows Vista or Windows 7 operating systems, right click the Carbware Setup Launcher Icon and select **Run as Administrator**. This will overcome the additional security features associated with newer versions.



- Enter your user details (Name & Organisation):

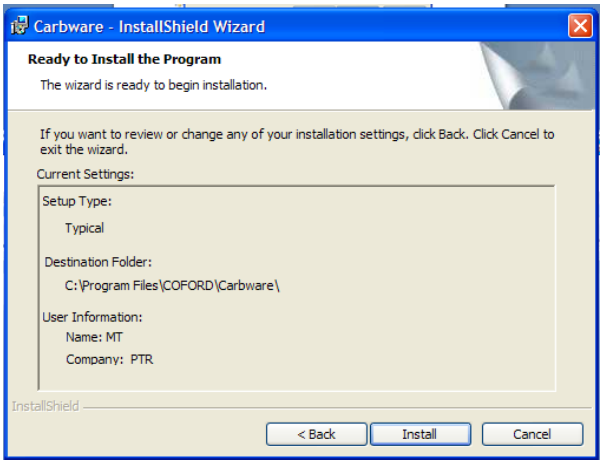


- Select the required Setup Type (select Typical):

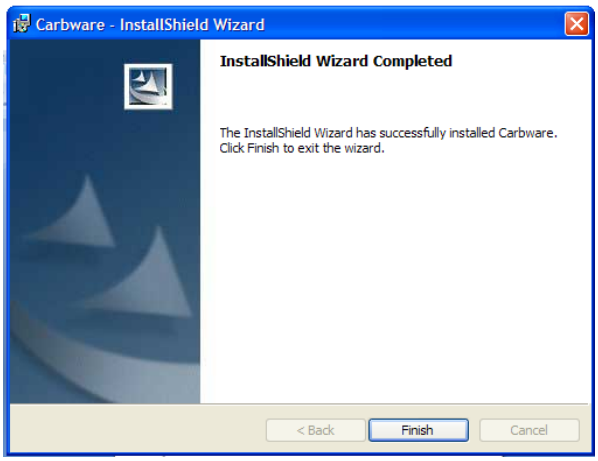

Carbware - InstallShield Wizard
Setup Type
Choose the setup type that best suits your needs.
Please select a setup type.
Typical
All program features will be installed. (Requires the most disk space.)
Minimal
Minimum required features will be installed.
Custom
Choose which program features you want installed and where they will be installed. Recommended for advanced users.
InstallShield
< Back
Next >
Cancel

- CARBWARE is now ready to be installed on your PC. Click ***Install*** to complete the installation. CARBWARE will be installed in the following directory:

  C:\Program Files\COFORD\Carbware

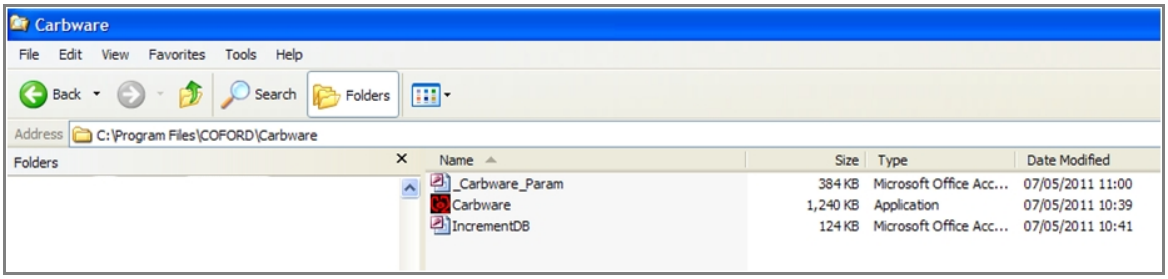


- When the installation is complete, click ***Finish***.

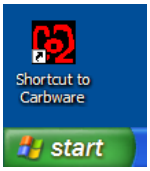

Carbware - InstallShield Wizard
InstallShield Wizard Completed
The InstallShield Wizard has successfully installed Carbware. Click Finish to exit the wizard.
< Back
Finish
Cancel

- Using Windows Explorer, check that the following three files have been successfully installed in the directory **C:\Program Files\COFORD\Carbware:**

  ~ _Carbware_Param *(Microsoft Office Access Database)*
  ~ IncrementDB *(Microsoft Office Access Database)*
  ~ Carbware *(Application)*



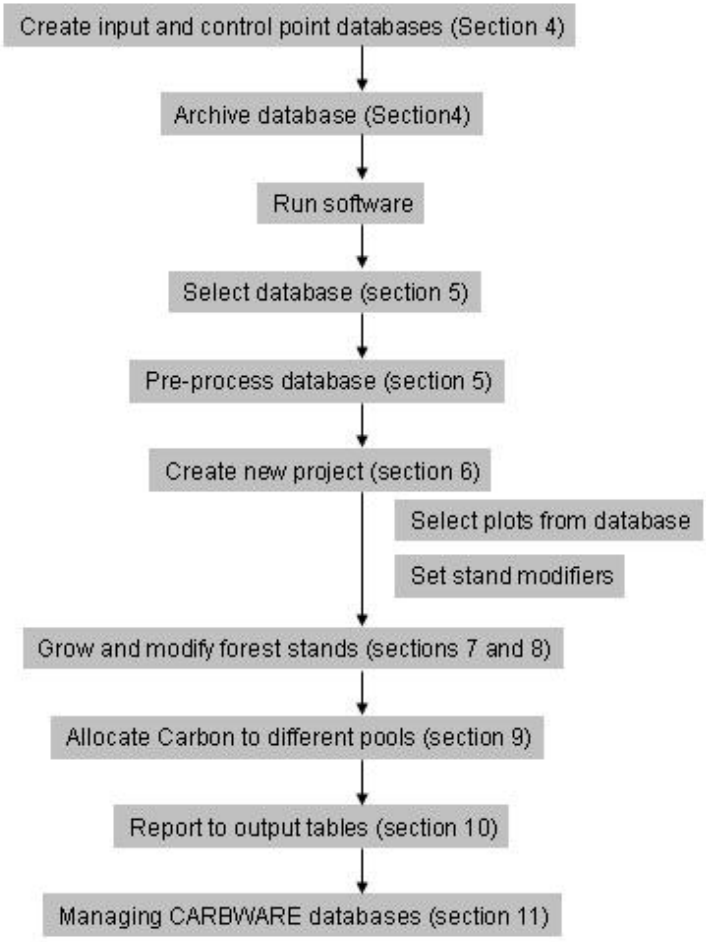
- A Shortcut Icon will be created automatically on your PC Desktop:



3. Overview of CARBWARE functionality

3.1 User quick start flow diagram

The flow diagram below illustrates the sequence of events and instructions the user should follow to efficiency utilise the software


Create input and control point databases (Section 4)
Archive database (Section4)
Run software
Select database (section 5)
Pre-process database (section 5)
Create new project (section 6)
Select plots from database
Set stand modifiers
Grow and modify forest stands (sections 7 and 8)
Allocate Carbon to different pools (section 9)
Report to output tables (section 10)
Managing CARBWARE databases (section 11)

3.2 Detailed functionality

The CARBWARE application runs off 3 core databases, which contain input data tables (represented as yellow boxes in Figure 2), intermediate output tables (green boxes), and archive and control point tables. The user must first create the input database. The nomenclature of the database must contain the prefix **Carbw** and be in Microsoft access format (e.g. **Carbw**ini2005**.mdb** see instillation disc). The other 2

databases, namely IncrementDB.mdb and Carbware_Parameters.mdb, are downloaded when the software is installed. The incrementDB stores intermediate output files (green boxes, Figure 2) when the growth, modification and allocation modules are run after a project is set up. The parameters database stores writing directories during the creation of the input (**Carbw**) database and assigns mortality probability thresholds which can be changed by the user. The instructions for creating compatible input databases for the software are described in section 4.

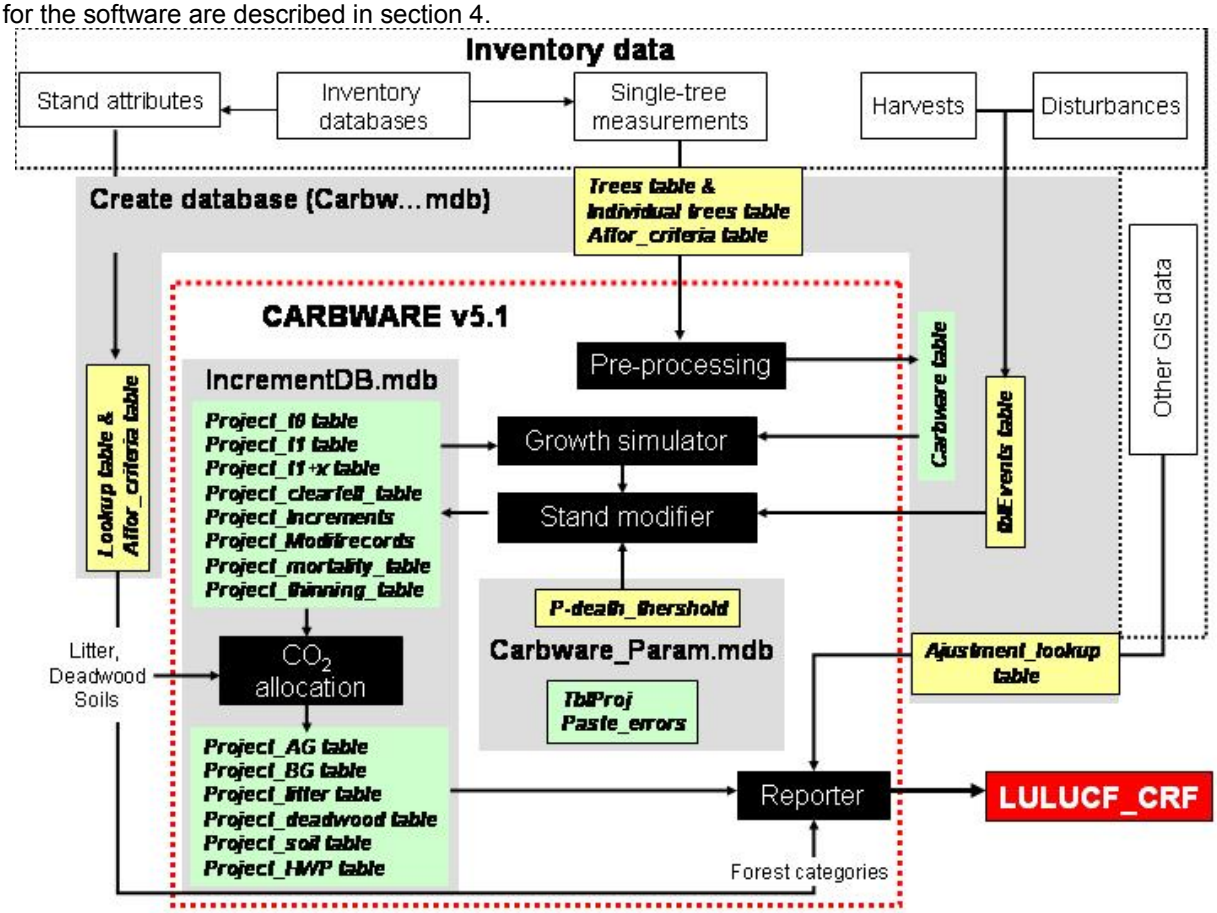


Figure 2: A schematic representation of the different databases (grey boxes) containing input tables (yellow boxes), which are used by software modules (black boxes) to derive intermediate output tables (green boxes) and the final common reporting format tables (CRF, in red). The input tables are generated by the users based on standard inventory information (clear boxes).

The CARBWARE software functions (represented as all activities in the red broken line border, see Figure 2) have the following features:

1) Options to select an already created database projects (i.e. **Carbw.mdb**) and create, delete or save projects (i.e. a series of plot data and scenarios used in a projection).
2) Software modules (shown in black boxes, figure 2), are the application steps which the user follows.
    a. **Pre-processing module**: This module processes the data into a format that can be used by the growth and modification models. The input tables are used to populate a new table called '**CARBWARE**', which is written to the created **Carbw**….database project. This data is derived from the ***Trees*** and ***individual_trees*** tables, which are created by the user (see section 4). Functions performed in this module include:
        i. Extraction of and formatting individual tree and plot data from the sample plot inventory data (see input requirements section 4)

ii. Computation of missing height, crown ratio, crown diameter values, which may not have been measured in the inventory plot(s) (see appendix 1B for description of functionality). DBH should be measured for every tree above a height of 1.3m. Heights should be measured for trees smaller than 1.3m.
iii. Classification of different species into the 6 cohorts for growth modelling
iv. Derivation of required parameters used in the growth and mortality modules (see appendices for description of models). These include parameters such as basal area, stocking, basal area of the larger trees (BAL), probability values for the likelihood that a tree may die in the next growth phase and crown competition factors.
v. Calculation of scaling up expansion factors in the case where all trees may not be measured in a plot and where systematic stratified tree sampling is performed (see Section 4). These values are used to adjust the stand level values, such as basal area and BAL.
vi. Classification and categorisation of tree status and age for input in to the growth and mortality model in the Growth simulator module.

b. **Growth simulator**: This module performs the growth simulations on an annual cycle up to 15 cycles. The growth models are based on distance independent single tree models using DBH as the growth output (see appendix 1C). Growth of trees with a DBH of less than 5 cm is modelled using a simple Chapman-Richards growth function with height as the growth output (Appendix C). **The stand modifier**: modifies individual tree and stand values after each growth iteration. The drivers for modification of individual trees or plot variables are derived from input tables (***tblEvents***, see Figure 2 & section 4), which control the number of trees removed due to harvest or mortality. For thinnings, trees are randomly removed in until the threshold basal area is reached. The virtual removal of individual trees from a list trees in the corresponding plot is controlled by a defined harvest basal area in a given year.
Note: if the same procedure is repeated it may remove different trees if a thinning event or mortality is repeated for the same plot.

The mortality of trees during a given growth cycle is derived from a probabilistic model (see appendix D). The probability threshold values can be defined by the user in the ***P_death_threshold*** table located in the installed **Carbware_parameters** data base. However, the user should refer to appendix D to understand the consequence of adjusting the default P value setting for each species cohort.

The outputs from the growth and modification modules are stored in the **IncrementDB**. For each project (assume file name is ***Project***), every growth and stand modification cycle is assigned a table (e.g. ***Project_t0*** or ***Project t1***). These intermediate tables are used for the next iteration if another growth cycle is prompted by the user or an allocation procedure is prompted. The I**ncrementDB** also writes tables which summarise any modification events, such as thinnings, clearfell or mortality of trees during a growth/modification cycle (e.g. ***Project_Thinning_table***). The field names and units of values of individual tables are reviewed in sections 7 and 8.

3) **CO_2 allocation and stratification**: the allocation module uses the intermediate growth output tables (described above Figure 2) to generate carbon stock estimates for the 6 major carbon pools.

The allocation module performs the following functions:

i. Converts tree measurements (DBH and H) to biomass components (see Appendix A)
ii. Sums all tree biomass components in the plot and normalises the units to 1 ha. This is done using the user specified plot sizes located in the ***lookup table*** located in the **Carbw..mdb** database.

iii. Allocates the transfer of carbon between the different 6 pools to simulate the flow between biomass (AG and BG), litter, dead wood, harvested and soil pools. The details of the C flow model are shown in appendix E. These outputs are written to the Increment DB using the project name as a prefix.

iv. Some of the initial C pools (at the plot level) have to be input by the user (the ***lookup table*** located in the **Carbw..mdb** database). These include initial litter and deadwood inputs in addition to the soils emission factors (see Section 4)

v. The biomass stock changes for aboveground (***Project_AG table***) and belowground biomass (***Project _BG***) are derived from the DBH and H values of individual trees using biomass algorithms (Appendix A). The biomass pools are aggregated to the plot level using information in the ***lookup table*** located in the **Carbw..mdb** database (created by the user see section 4). Detailed calculation steps for the estimation of the biomass pool changes are shown in Appendix E, equations 1 to 9. The losses from the biomass pool due to harvest, obtained from the ***Project_thinning*** and ***clearfell tables,*** are calculated using biomass algorithms. These values are scaled up to the plot level using the scaling factor (in *CARWBARE table*) and transferred to the ***Project_HWP table***. Harvest residue left on site is transferred to the ***Project_deadwood*** or ***Project_litter tables***. Biomass from mortality is either transferred to the deadwood or litter pool (***Project_deadwood*** or ***Project_litter tables***) depending on the size (DBH of the trees, see Appendix E).

vi. The litter pool stock changes are obtained from the initial input values (lookup table) and functions in the module described using equations 9-12 in appendix E.

vii. The deadwood pools are calculated using the initial data inputs from the user lookup table (see section 4) and functions described in equations 13-15, appendix E.

viii. The soil pools are calculated using plot area, soil classification and emission accumulation factors described by the user in the look up table (see section 4 and appendix E).

ix. The HWP pool is derived using the biomass of harvested trees allocated from the biomass pools. This module does not calculate HWP because the current rules for accounting have not been finalised. However, the table does supply the HWP inputs for supplementary analysis using different models or software (see section 4)

4) **Reporter module**
Final output tables are generated in the reported module using the common reporting format as outlined by the UNFCCC (see section 10)

4. Data input requirements

Input data must be stored in a MS access database in specific tables under specific field headers. The MS access database should be named with the prefix Carbw…. ending with the year of inventory. For example Carbwini2005 is the example database from the 2005 inventory provided on the instillation disc. The format of headers and data entries should be in the correct format and units for the software to operate properly.

4.1 Forest inventory database (i.e Carbw…200X)

No specific forest inventory design is required for CARBWARE to function. However, the inventory should provide mandatory information listed in the table 1 (also see example database (**Carbwini. 2005.mdb**) on

instillation disc or web folder). Specific details on how the data is obtained are dealt with in the preceding text sections. Example databases are provided in the enclosed cd to illustrate data format and layout.

It is important that the precise field names (case sensitive), properties of fields and order of fields in the specific tables are identical to the examples provided to ensure that the software run properly, Failure to comply with these formats will result in error warnings which are logged in a text error files located in the destination folder where the software is installed.

Table 1: The required information filed names, properties, units required and field order in tables located in the **Carbwini.2005.mdb** database.

Data	Description	Requirement [2]	Table	Units/Format
IDPlots	Plot ID number	M	Individual Trees and Trees	Numeric (e.g. 1 to 100000) does not have to be continuous or in any order
X_m	X co-ordinate of tree in m from local origin point	O	Trees	Numeric, positive or negative
Y_m	Y co-ordinate of tree in m from local origin point	O	Trees	Numeric, positive or negative
IDSmallTrees	Small tree ID	M	Individual Trees	Numeric, always 1
ID	Tree ID	M	Individual Trees, Trees	Numeric. In Trees table small individual trees should be listed as 900X, where X is the Small tree ID from Individual tree table and corresponding plot
ProcessCode	Processing notification key	O	Individual Trees, Trees	QC of post data capture processing functions in Irish NFI
FieldStatus	Processing notification key	O	Individual Trees, Trees	QA/QC of post data capture processing functions in Irish NFI
Edit_date	Date captured data was edited	M	Individual Trees, Trees	QA/QC of post data capture processing functions in Irish NFI
Edit_user	User who performed edit	M	Individual Trees. Trees	QA/QC of post data capture processing functions in Irish NFI
Z_m	Z (azimuth) co-ordinate of tree in m from local origin point	O	Trees	Numeric, positive or negative
XMeasurepoint_m	Crown measurements	O	Trees	Specific NFI data not currently used
YMeasurepoint_m	Crown measurements	O	Trees	Specific NFI data not currently used
ZMeasurepoint	Crown measurements	O	Trees	Specific NFI data

[2] M = mandatory, O=optional, N is not required at present **but fields with names must be incorporated in the table even if the cells are empty**

Data	Description	Requirement	Table	Units/Format
XCentreCrownProj_m	Crown measurements	O	Trees	Specific NFI data not currently used
YCentreCrownProj_m	Crown measurements	O	Trees	Specific NFI data
SmoothedCrownProj	Crown measurements	O	Trees	Specific NFI data not currently used
Slant_Azymuth_deg	Tree slant	O	Trees	Specific NFI data not currently used
Slant_Angle_deg	Tree slant angle	O	Trees	Specific NFI data not currently used
Stem_volume_m3	Calculated stem volume in m3	O	Trees	Specific NFI data not currently used
CrownProj_Area_m2	Projected crown area	O	Trees	Specific NFI data not currently used
Crown_Volume_m3	Crown volume	O	Trees	Specific NFI data not currently used
Crown_Surface_m2	Crown surface area	O	Trees	Specific NFI data not currently used
DBH_mm	Diameter at 1.3m height	M	Trees	Numeric in mm, no decimal points
Height_m	Tree Height (mandatory for small trees, random sample for big trees in Trees table were DBH is measured)	M	Individual Trees, Trees	Numeric in m to one decimal point
CrownBase_m	Height at base of living crown (when available, recommended but not mandatory)	O/M	Trees	Numeric in m to 1 decimal point
DeadCrBase_m	Height at base of dead crown	O/M	Trees	Numeric in m to 1 decimal point
Tree_Length_m	Length of tree in m, for slanted trees (mandatory if crown_base_m is reported	O/M	Trees	Numeric in m to 1 decimal point Numeric
Crown_Length_m	Length of crown in m (i.e Tree length – Crown_base; mandatory if Crown_base is reported	O/M	Trees	Numeric in m to 1 decimal point Numeric
NewOrMissingTree	Missing or new tree ID	O	Trees	Specific NFI data not currently used
DBH1_mm	Alternative DBH measurement	O	Trees	Specific NFI data not currently used
Species	Species code	M	Individual Trees, Tree	Numeric, user defined lookup codes (see species look up and cohorts)
DBH2_mm	Alternative DBH measurement	O	Trees	Specific NFI data not currently used
StandLayer	Stand layer code	O	Trees	Specific NFI data not currently used
Age	Tree age in years	M	Individual Trees, Trees	Numeric, no decimal point

Data	Description	Requirement	Table	Units/Format
BreastHeight_cm	Height at which DBH is measured in cm	O	Trees	NUMERIC NO DECIMAL PLACE
Diameter03h_mm	Diameter at 1/3 of stem length	O	Trees	Specific NFI data not currently used
HDiamter03h_m	Height in m at Diamter03h	O	Trees	Specific NFI data not currently used
DeadTree	Tree dead or alive	M	Trees	Numeric, pre defined; 100 for alive, 200 for recently dead, 300 for dead longer than one year
TreeBreak	Tree break	O	Trees	User defined Numeric lookup table describing stem break
StemRot	Tree breakage	O	Trees	User defined Numeric lookup table describing stem rot
ForkTree	Tree forking	O	Trees	User defined Numeric lookup table describing forked trees
SocialStatus	Dominance/suppression etc	O	Trees	Specific NFI data not currently used
IUFROheight		O	Trees	Specific NFI data not currently used
IUFROvitality		O	Trees	Specific NFI data not currently used
IUFROgrowth		O	Trees	Specific NFI data not currently used
CrownShape		O	Trees	Specific NFI data not currently used
StemStraightness		O	Trees	Specific NFI data not currently used
Pruning		O	Trees	Specific NFI data not currently used
Branchiness		O	Trees	Specific NFI data not currently used
Shapping		O	Trees	Specific NFI data not currently used
StemDamageDegree		O	Trees	Specific NFI data not currently used
StemDamageAge		O	Trees	Specific NFI data not currently used
PeelingDegree		O	Trees	Specific NFI data not currently used
PeelingAge		O	Trees	Specific NFI data not currently used
RootDamageDegree		O	Trees	Specific NFI data not currently used
RootDamageAge		O	Trees	Specific NFI data

Data	Description	Requirement	Table	Units/Format
OtherDamage		O	Trees	Specific NFI data not currently used
HeightSampleTree		O	Trees	Specific NFI data not currently used
D03hSampleTree		O	Trees	Specific NFI data not currently used
VitalitySampleTree		O	Trees	Specific NFI data not currently used
BaseDBH_mm		O	Trees	Specific NFI data not currently used
CalcHeight_m	Calculated tree height from independent models	O	Trees	Numeric
Vol_BFC_m3	BFC volume of tree	O	Trees	Specific NFI data not currently used
Adjust_Vol_BFC_m3	Adjusted volume	O	Trees	Specific NFI data not currently used
Repre_Vol_BFC_m3	Representative volume	O	Trees	Specific NFI data not currently used
TreeNumber	Number of trees measured, default 1	M	Trees	Numeric, no decimal places
BasalArea_m2	Individual tree basal area	M	Trees	Numeric up to 15 decimal places in m2
AdjustBasalArea	NFI adjustment, default = BasalArea_m2	M	Trees	Numeric up to 15 decimal places in m2
RepreBasalArea_m2	BasalArea_m2 * ExpansionFactor (see below)	M	Trees	
TimberHeight_m	Height of timber	O	Trees	Numeric in m
RepreTreeNumber	Number of trees the individual tree measurements represent (see box 1 stratified sampling)	M	Trees	Numeric up to 15 decimal places (no. of trees no units)
ExpansionFactor	Number of trees represented by the measured tree (this applies to systematic partial sampling of inventory plots (as above)	M	Trees	Numeric up to 15 decimal places
RepreArea_ha	Representative area for each tree based on volume, the sum of the representative areas is equal to the plot size, if trees are present	O	Trees	Specific NFI data not currently used
RepreHeight_m	Representative height for trees used for aggregation in NFI	O	Trees	Specific NFI data not currently used
DiameterGroup		O	Trees	Specific NFI data not currently used
DiameterClass5		O	Trees	Specific NFI data not currently used
DimensionClass5		O	Trees	Specific NFI data

Data	Description	Requirement	Table	Units/Format
AgeClass10_150		O	Trees	Specific NFI data not currently used
AgeClass20		O	Trees	Specific NFI data not currently used
SpeciesGroup		O	Trees	Specific NFI data not currently used
IDSubcircle		O	Trees	Specific NFI data not currently used
GrowthStage		O	Trees	Specific NFI data not currently used
ConiferBroadleaf		O	Trees	Specific NFI data not currently used
NativeNonNative		O	Trees	Specific NFI data not currently used
AgeClass10_60		O	Trees	Specific NFI data not currently used
SlendernessRatio		O	Trees	Specific NFI data not currently used
SlendernessRatioCategory		O	Trees	Specific NFI data not currently used
AgeClass5_60		O	Trees	Specific NFI data not currently used
DBH_cm	DBH_mm/10	M	Trees	Numeric, 1 decimal place
BranchinessJR		O	Trees	Specific NFI data not currently used
RotationTypeJR		O	Trees	Specific NFI data not currently used
ThinStatusJR		O	Trees	Specific NFI data not currently used
GrowthStageJR		O	Trees	Specific NFI data not currently used
DiameterClass1		O	Trees	Specific NFI data not currently used
AgeCalss15_25		O	Trees	Specific NFI data not currently used
AgeClass10_60JR		O	Trees	Specific NFI data not currently used
AboveBiom_t		O	Trees	Specific NFI data not currently used
Adjust_AboveBiom_t		O	Trees	Specific NFI data not currently used
Repre_AboveBiom_t		O	Trees	Specific NFI data not currently used
BelowBiom_t		O	Trees	Specific NFI data not currently used
Adjust_BelowBiom_t		O	Trees	Specific NFI data not currently used
Repre_BelowBiom_t		O	Trees	Specific NFI data not currently used
TotalBiom_t		O	Trees	Specific NFI data not currently used
Adjust_TotalBiom_t		O	Trees	Specific NFI data

Data	Description	Requirement	Table	Units/Format
Repre_TotalBiom_t		O	Trees	Specific NFI data not currently used
AboveCarbon_t		O	Trees	Specific NFI data not currently used
Adjust_AboveCarbon_t		O	Trees	Specific NFI data not currently used
Repre_AboveCarbon_t		O	Trees	Specific NFI data not currently used
BelowCarbon_t		O	Trees	Specific NFI data not currently used
Adjust_BelowCarbon_t		O	Trees	Specific NFI data not currently used
Repre_BelowCarbon_t		O	Trees	Specific NFI data not currently used
TotalCarbon_t		O	Trees	Specific NFI data not currently used
Adjust_TotalCarbon_t		O	Trees	Specific NFI data not currently used
Repre_TotalCarbon_t		O	Trees	Specific NFI data not currently used
Diameter_mm	Diameter at 1.3m height (mandatory if tree is > 1.3 m high)	M	Individual Trees	Numeric in mm, no decimal points
Origin	NFI edit code	O	Individual trees	Specific NFI data not currently used
NFI_ID	Plot ID the same as ID plots (must be identical numbering	M	Afor_Criteria	Numeric
Kyoto_ID	Forest classification. Article 3.3 or 3.4 forests[3]	M	Afor_Criteria	Numeric either 3.3 or 3.4
PlotID	Plot ID cross referenced to NFI_ID and IDplots	M	Lookup	Numeric
Area_ha	Area of plot	M	Lookup	Numeric in ha to 2 decimal points
County	County where plot is located	M	Lookup	Numeric, user defied lookup codes
Ownership	Ownership of forest	M	Lookup	Numeric look up codes, user defined
Landusefield	Landusetype (optional)	O	Lookup	Initial dead stump C pool (mandatory for each plot, can be derived form measurement or independent models)
Forest_category_ID	Forest type	M	Lookup	Numeric look up code user defined, used to aggregate forest types

[3] Article 3.3 forests are those established after 31st December 1989 and article 3.4 forests are established before 31st December 1989

Data	Description	Requirement	Table	Units/Format
Litter_C_tn_1	Initial Litter C pool (mandatory for each plot, can be derived form measurement or independent models)	M	Lookup	Numeric , expressed in t C per plot area e.g. 0.002145 tC per 0.05ha
Stump_Ctn	Initial dead stump C pool (mandatory for each plot, can be derived form measurement or independent models)	M	Lookup	Numeric , expressed in t C per plot area e.g. 0.002145 tC per 0.05ha
Deadlog_Ctn	Initial dead logs C pool (mandatory for each plot, can be derived form measurement or independent models)	M	Lookup	Numeric , expressed in t C per plot area e.g. 0.002145 tC per 0.05ha
CARBWARE_soil	Soil categories (mandatory)	M	Lookup	Numeric look up codes, user defined
Soil_EF_Category	Soil emission categories. Child layer of Siol category (i.e. each CARBWARE soil category will have a shared or individual Soil_EF_category)	M	Lookup	Numeric look up codes, user defined Default 1= peats 2= peaty-mineral soil 3=mineral soils
Drainage	Description of site drainage	O	Lookup	Numeric look up codes, pre-defined: 100-excessive drainage 200-well drained 300-moderate to well drained 400-imperfectly drained 500-poorly 600-very poorly 700-undefined (limestone pavement)
SoilDepth_cm	Mineral soil depth in cm	O	Lookup	Numeric
PeatDepth_cm	Peat/organic soil depth	M	Lookup	Numeric
EPA_SoilGroup	EPA soil or other classification codes	O	Lookup	Numeric look up codes, user defined
EF_soil	Emission factor for soils	M	Lookup	Numeric, negative value represents an uptake of C, positive values represent an emission (e.g. peat soils) Values in t C ha^{-1}
Equil_Time	Time taken (yeas) for soil to reach equilibrium	O	Lookup	Numeric

Data	Description	Requirement	Table	Units/Format
Net_Soil_DCtn_1	Soil emission factor at the plot level	M	Lookup	EF_soil at plot area e.g. 0.034 tC for 0.05 ha (positive values represent emissions, negative values are removals)
MineralNO2_EF	Mineral soil N2O emission following drainage	O	Lookup	Numeric, in tCO2 eq expressed on the size of the plot
Organic_poor_NO2_EF	Poor (nutrient poor) organic soil N2O emission following drainage (e.g. peats)	O	Lookup	Numeric in tCO2 eq expressed on the size of the plot
Organic_rich_NO2_EF	Nutrient rich organic soil N2O emission following drainage		Lookup	Numeric in tCO2 eq expressed on the size of the plot
NO2T	Total soil N2O emission following drainage	O	Lookup	Numeric in tCO2 eq expressed on the size of the plot
PlotID	ID of plot, must be the same as those used in trees, individual trees, afor_criteria and lookup tables	M	tblEvent	Numeric
Year	Year thinning or clearfell is planned	M	tblEvent	Numeric e.g. 2007
Event	Thinning or cleafell	M	tblEvent	Numeric code: 100= clearfell, 200 = thinning
Reduction	Amount of basal area per ha removed	M	tblEvent	Numeric, 1 decimal point. Note plot will not be thinned or clear felled if basal areas exceeds standing basal area at time of harvest

4.1.1 Required Inventory Database Structure & File Naming Conventions

Carbware functionality is strongly dependent on good inventory data. The sampling strategy used will depend on national or regional circumstances so CARBWARE has been designed to facilitate such differences as long as the input field are presented in a consistent manner. The initialisation process requires 3 major tables in an MS Access database named with the prefix **Carbw…** and suffix must be the year the inventory data was recorded e.g. **Carbw**ini_**20XX (the characters in bold are mandatory).**
It is also important that the table field headers are identical to the examples provided; otherwise call up functions based on field header titles can not be executed.
Note if a header is missing or incorrectly entered a warning and error file will be created outlining the nature of the error

Data formats
All tables in the Access database should not be linked but imported into Access. The table and field names and data formats must be adhered to.

4.1.1.1 The 'Trees' table (specific data on mandatory fields)

This table contains information pertaining to individual trees with a diameter at breast height (i.e 130cm) of 7cm or greater. The Trees table should contain the following headers with specified information (also see Table 1):

a) **IDPlots**: the plot number
b) **ID**: Tree identification number. These should be unique starting at 1 (not necessarily in numerical order). If there are trees within the plot with a DBH less than 7cm then these should be recorded in the IndividualTrees table. However all of these trees should also be identified in the Trees table. The Tree table ID should be 900x (where x is the tree ID in the IndividualTrees table (e.g. if the tree ID in the IndividualTrees table is 1 then the ID in the Trees tae should be 9001)
c) **Edit_date**: the date and time the data was entered or modified e.g. 16/07/2005 12:34:56
d) **Edit_user**: user who input or changes the data. SYSTEM should be used as a default.
e) **DBH_mm**: DBH at 130cm in mm for all trees in the Trees table. The growth models have been parameterised using DBH at 130 cm if other conventions are used then this will create bias in the projected C stock changes. The software does facilitate a partial sampling system, but if a tree is identified in the Trees table the DBH and corresponding data must be entered.
f) **Height_m**: the corresponding tree height in m. It is not necessary to provide the height of all trees when DBH is measured. However, a complete list of tree height will reduce modelling error since the software runs algorithms to calculate missing height data.
g) **CrownBase_m:** The height at the base of the living crown in meters. This must me measured if total height in measured.
h) **DeadCrBase_m:** The height at the base of the dead crown in meters. This must be measured if total height in measured.
i) **Tree_Length_m:** the total tree length form the stump to the highest point on the crown in m. This would be equal to tree height if the tree is not slanted.
j) **Crown_Length_m:** This is the **Tree_Length_m** minus the **CrownBase_m**
k) **Species:** These are codes specifying the species. It is important to use the same codes and classification of species cohorts so the software can allocate a given tree in to the correct cohort where specific algorithms are applied. If there is a species not present in the list use a code corresponding to the next most similar species.

Note: The growth models are empirically derived so application of models to trees outside the Republic of Ireland or the UK will introduce model error. However, CARBWARE developers will parameterise models representative of local ecological and climatic zones if requested and the appropriate calibration data is available.

For a full list of species, lookup codes and corresponding cohorts see model_cohort_lookup.xls on instillation disc.

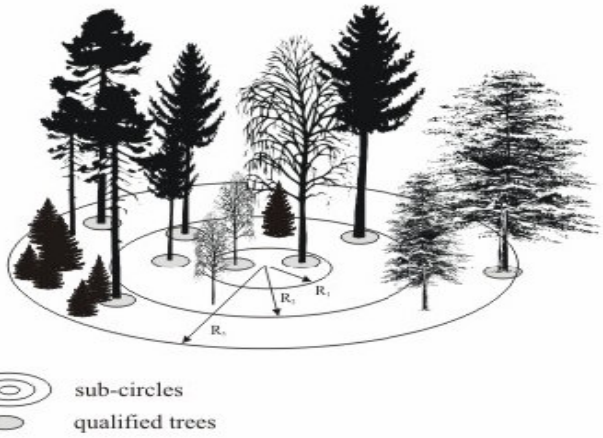
l) **Age:** tree age in years. The growth models use are age and distance independent, bit this information is used to derive variable such as litter or dead wood pools and to allow aggregation of data in the reporting manual
m) **DeadTree:** These are look-up code specifying if the tree id dead and how long ago it died (see Table 1 for details). This is used for initialising the mortality algorithms.
n) **CalcHeight_m:** If the inventory uses another method to calculate the height of tree which are not measured this can be entered here
o) **TreeNumber:** This is the number of trees represented for this entry. Not to be confused with expansion factor. The default is 1 unless trees are listed in the IndividualTrees table. So if the tree ID is 9001 with 6 trees in the plot entered in the IndividualTress table then the TreeNumber would be 6. This value is used to validate the data when the Trees and IndividualTrees table is merged, when the CARBWARE pre-processing table is created.

p) **ExpansionFactor**: the number of trees the sampled tree represents (see information Box 1). If all trees in a plot are sampled and entered then the Expansion Factor is 1.
q) **BasalArea_m2**: is the individual tree basal area in m2.
r) **DBH_cm**: DBH_mm divide by 10
s) **RepreBasalArea_m2**: is the BasalArea_m2 x ExpansionFactor

Box 1: Stratified sampling of trees in a plot

The inventory may choose to take a stratified sample of trees within a plot to reduce time and expenses. For example the Irish inventory uses the sampling approach shown in Figure 2. In this case all trees with a DBH of less than 70mm are only measured in the 3m inner sub circle. Trees with a DBH of 70 to 120 mm are measured within in the second inner circle and all trees with a DBH greater than 200 mm are measured within the circular plot.

This sampling method, in conjunction with an assumption of homogeneous spatial diameter distribution, informs the calculation of a sampling weight or *expansion factor* which is used to allow for the possibility that some trees on a given plot were not sampled. The expansion factor is inversely proportional to the prior probability of a given tree's inclusion in the sample, based on the trees diameter class. Each tree in the sample is thus duplicated by a number of times equal to its expansion factor. This duplication is allowed for when calculating plot-level derived variables, e.g. Density or Basal area, by incorporating the expansion factor into the equations. For example, the estimated number of trees on a plot with a single sampled tree of 8cm is $(12.62/3)^2 = 17.69$. Therefore 1 measured tree, with a diameter less than 70mm in the 3m inner circle will represent 17.69 tree and have an Expansion factor of 17.96. Where all trees are measures (e.g. DBH of 200mm) then the Expansion factor is 1. See Figure 2 for an explanation.



	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 3. The NFI sampling scheme at the plot-level. The *expansion factor* for a tree in the *i*th diameter class is $(R_3/R_i)^2$

Note: if all trees are measured in a plot then an expansion facto of 1 is applied

For accurate projection of C balance, it is advised to use a sampling regime which measures all trees in the plot since CARBWARE does not perform in-growth functions. This related to a tree which may not have been measured in a given inventory cycle because it does not meet the diameter threshold in the particle concentric plot. If the tree were to grow and the diameter now meets the required threshold, then the tree should be measured and include in calculations. However, CARBWARE does not facilitate the detection of the tree due to in-growth.

The errors associated with omission due to in-growth are yet to be quantified, so a complete sample of trees in a plot is recommended

4.1.1.2 The 'IndividualTrees' table

As mentioned previously this table contains information on trees with a DBH of less than 7cm. This is required because additional information is captured in this case. In this table all entered trees must have a measured tree height and DBH if present. These tables are also used to create virtual plots from establishment. The IndividualTrees table should contain the following headers with specified information (also see Table 1):

a) **IDPlots**: This must correspond with the IDPlot number in the Trees table
b) **ID:** small tree ID starting with number 1, each tree for a given species should be consecutively numbered. If there are mixed species in a plot then should be
c) **Edit_date**: the date and time the data was entered or modified e.g. 16/07/2005 12:34:56
d) **Edit_user**: user who input or changes the data. SYSTEM should be used as a default.
e) **Species:** These are codes specifying the species. It is important to use the same codes and classification of species cohorts so the software can allocate a given tree in to the correct cohort where specific algorithms are applied. If there is a species not present in the list use a code corresponding to the next most similar species.

Note: The growth models are empirically derived so application of models to trees outside the Republic of Ireland or the UK will introduce model error. However, CARBWARE developers will parameterise models representative of local ecological and climatic zones if requested and the appropriate calibration data is available.

For a full list of species, lookup codes and corresponding cohorts see model_cohort_lookup.xls on instillation disk

f) **Height_m**: tree height in meters, all trees should have a measured height
g) **Diameter_mm**: diameter of trees at 130cm. If tree are less than 139cm high then the cell should be left blank
h) **Age**: tree age in years.

4.1.1.3 The 'Lookup' table

The lookup table contains plot specific information (one entry per plot), such as the size of the sample plot an characteristics used for aggregation and reporting final model outputs. Some of these values can be user defined to facilitate different software users. However, the field header and table format should be identical to the example provided.

a) **PlotID**: this must correspond with the IDPlot number in the Trees and IndividualTrees tables.
b) **Area_ha**: the sample plot area, e.g. using the example in Box 1 the plot is 0.05 ha
c) **County**: these are user defined lookup codes (must be numeric) used to agreegating final data in to regional categories. This does not have to be counties but the field header should not be changed.
d) **Ownership**: A user defied lookup code for describing forest owner categories
e) **Forest_category**: this can be user defined to categorise plots under different forest types. For example the Irish UNFCCC reporting system uses the following categories

Table.2. Default forest category codes used.

Forest_Category_Code	Forest_Category_Description
1	Spruce (Pure). Mainly Sitka and Norway spruce
2	Pine (Pure). Prodominantly Scots and lodgepole pine
3	Larch (Pure)
4	Other conifers (Pure)
5	Fast growing broadleaves (Pure) such as ask, Alder, Sycamore, Birch
6	Slow growing broadleaves (Pure) such as Oak and Beech
7	Conifer mixes
8	Broadleaf mix
9	Conifer/Boradleaf mix
10	Open areas including biodiversity areas, roads within the forest boundary
11	Blown areas subjected to windthrow
12	Scrub, felled or failed areas (planted and unplanted)
13	New afforestation after 2006
14	Natural succession and regenreating land
101 to 115	Harvested areas. E.g 101 are harvested spruce areas
200	Burned areas

Forest stands were considered to be pure if one species represents 80 % or more of the canopy

f) **LanduseField**: not mandatory

g) Litter_C_tn_1: This is the initial litter carbon pool expressed per unit area of the plot (tC per plot), which is user defined. If no data is available then a look up table can be used to derive the value based on forest category (table 2) and age of stand (see Cpool_lookup_t0.xls, litter worksheet on instillation disc)
Note: the look up value is in tC per ha and must be normalised to the area of the plot, e.g for a 0.05ha plot the look up values must be multiplied by 0.05)

h) Stump_Ctn: This is the initial litter carbon pool expressed per unit area of the plot (tC per plot), which is user defined (range 0 to 26 t C per ha). The data is derived from measurements of stump volume and decays class where stump carbon = volume x wood density(0.4 default) x decay constant for different decay classes (0.98 to 0.48) x a C fraction (0.5 default). If no data is available then a look up table can be used to derive the value based on forest category (table 2) and age of stand (see Cpool_lookup_t0.xls, stumps worksheet on instillation disc)

i) Deadlog_Ctn: This is the initial litter carbon pool expressed per unit area of the plot (tC per plot), which is user defined (range 0 to 200 t C per ha). The data is derived from measurements of dead logs and decay class data where log carbon = volume x wood density (0.4 default) x decay constant for different decay classes (0.98 to 0.48) x a C fraction (0.5 default). If no data is available then a look up table can be used to derive the value based on forest category (table 2) and age of stand (see Cpool_lookup_t0.xls, deadlog worksheet on instillation disc)

j) **CARBWARE_soil:** Soils are sub categories according to soil types. In the example database there are 7 categories

k) Soil_EF_category: Soils are sub categories according to soils emission factors applied to different soils groups. In the example database there are 3 categories, mineral, organo-mineral and peat soils.

l) Drainage pre- defined:100-excessive drainage; 200-well drained; 300-moderate to well drained; 400-imperfectly drained 500-poorly; 600-very poorly; 700-undefined (limestone pavement) These are used for N20 emission calculations

m) Soil_depth_cm: Soil depth in m

n) **Peat_depth_cm** Soil depth in m is used to calculate the emissions from organo-mineral soils. In the example database, soils with a peat depth less than 60 cm are defined as organo-mineral and the emission factor is reduced proportionally according to peat depth

o) **EF_soil:** this is the emission factor in t C per ha (positive for emissions) or soil sequestration for mineral soils (negative for sequestration, if available). The current models does not apply emissions or reductions for mineral soils because current science suggest there is no significant change over a 20 year transition

p) **Equilibrium time:** This is the transition time for the application of soil EF, not functional in this version
q) **Net_Soil_DCtn_1:** EF x the area of the plot x (Peat_depth_cm/60, only if peat depth is < 60 cm)
r) **MineralNO2_EF**: Not included in current version
s) **Organic_poor_NO2_EF**: Not included in current version
t) **Organic_rich_NO2_EF**: Not included in current version
u) **NO2T**: Not included in current version

4.1.1.4 The 'tblEvents' table

The Events table instructs the software when to harvest specific plots and specifies the basal areas to be removed. See table 1 for details.

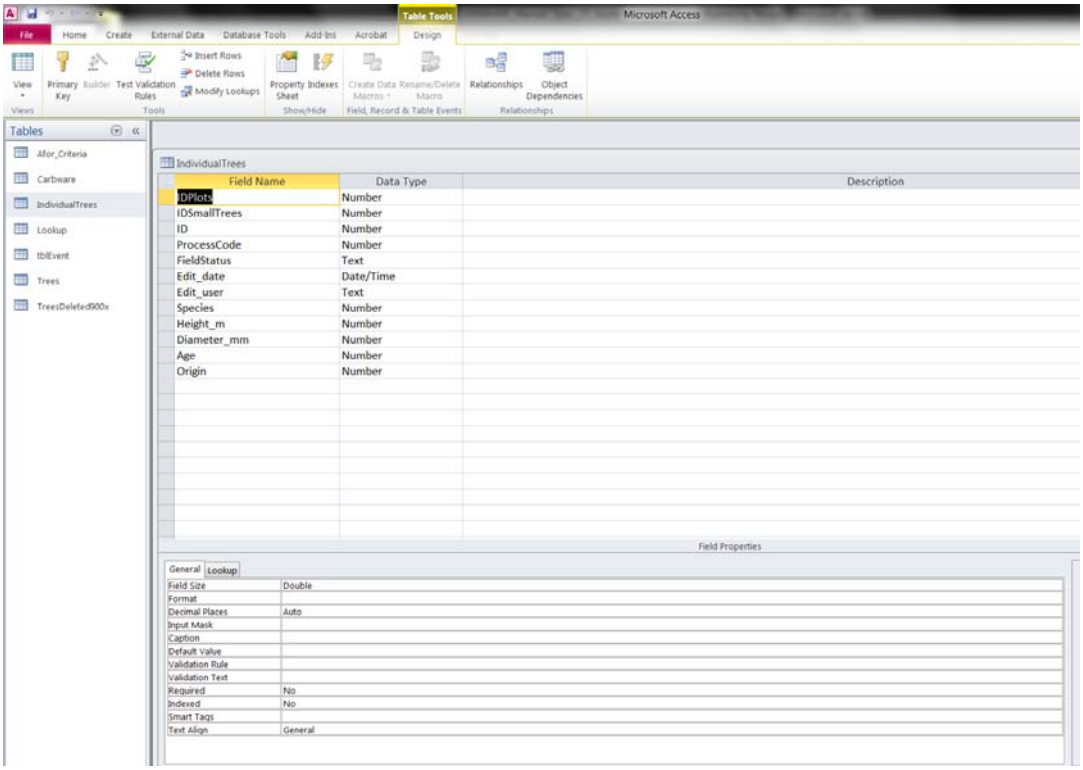
a) **PlotID**: must be the same as ID plot in other tables
b) **Year:** is the year when the harvest occurs, the harvest takes place after a growth cycle at the end of the year
c) **Even**t: defines a thinning (200) or clear fell (100) harvest
d) **Reduction**: is the basal area per ha removed. For clear fells all the trees are removed regardless of the target basal area. For thinning, trees are randomly removed until the threshold basal area is reached.
   Note that a thinning will not be executed if the thinning basal area is greater than the standing basal area. We recommend that preliminary runs are performed to check if the correct basal area reduction is applied at thinning.

4.1.1.5 The 'Afor_Criteria' table

The afor_criteria table is used to pre-sample the database when creating a project. This allows for quick selection of plots that fall into the UNFCCC reporting categories under articles 3.3 (post 1990) and 3.4 (pre-1990 forests) under the Kyoto protocol.

Field names and data formats

The screen shot of the Individual trees table below shows the precise field names, order of field and data formats which must be adhered to. The field properties can be viewed from Access using the **design view** option. See the example Carbwini.2005 database on instillation disc for reference.



4.2 Stand modification options

Stand modifications include mortality, and harvest. The extent of these modifications can be set in the P_death-threshold table (mortality) or tblEvent (thinning and clearfell, see 4.1.1.4). Alternatively the project can be run by not selecting any one of the modification options (see section 8). This is useful if one needs to establish the maximum increment or basal area if no mortality or harvests occur.

4.2.1 Mortality probability threshold options

Mortality is modelled based on a binary indicator of mortality (arbitrarily, 1 = tree dead at time of DBH measurement, 0 = tree alive). The default probability threshold (p) of a tree being dead was derived from analysis shown in appendix 1D. However, the user can change the p value for the 6 different cohorts in the P_Death_thresholds table in _Carbware parameter database (refer to appendix 1D for guidance). It is recommended that the minimum and maximum range (0, no mortality -0.2 or max mortality) should not be exceeded.

5 Pre-processing of Forest Inventory Data

Please refer to the example database provided on the Installation CD (Carbwini2005.db) for all software steps. Remember to always save a copy of your original inventory database file (e.g Carbwini2005_Raw_Data.db) before pre-processing is performed because tables in the database are modified during pre-processing and original database formats will be lost.

5.1 Selecting the required Forest Inventory Database

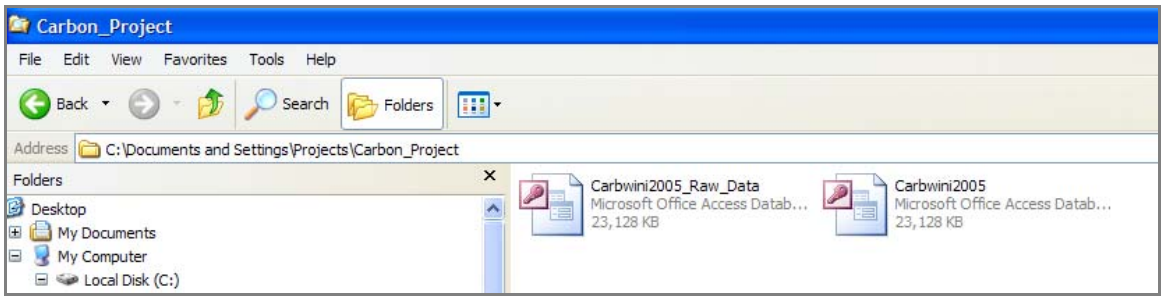
Before pre-processing your forest inventory data using Carbware software, it is important to conduct some basic file management operations in order to maintain the format of your original inventory database:

- Using Windows Explorer, **create a new project folder** in a location on your hard drive where you normally store your files.

  e.g. C:\Documents and Settings\Projects\Carbon_Project

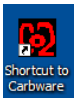
- Save a copy of your original MS Access inventory database file in this new directory

  e.g. C:\Documents and Settings\Projects\Carbon_Project\Carbwini2005.db

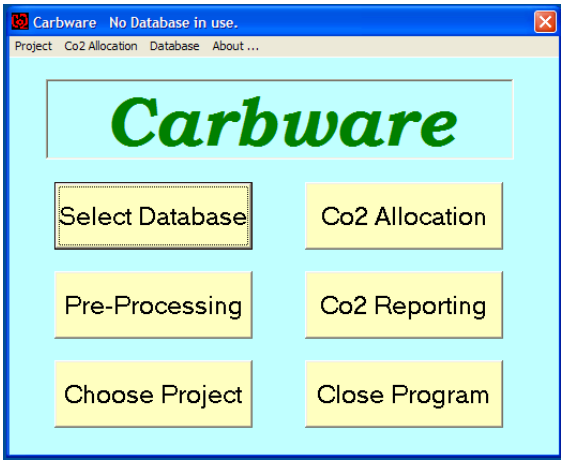


Important: Ensure that your inventory database is correctly structured and named, in accordance with guidelines presented in Section 4 of this manual.

- Start the CARBWARE programme by double clicking the Shortcut Icon on your PC Desktop

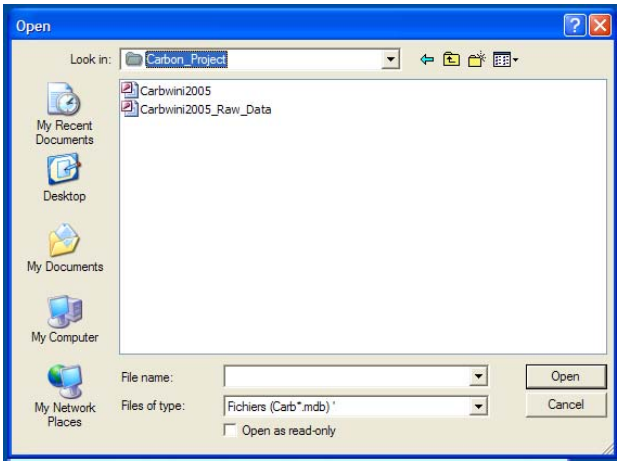


- You will see the following **Main Menu** screen:



- Click on the **Select Database** button and navigate your PC filing system to locate and open the required inventory database:

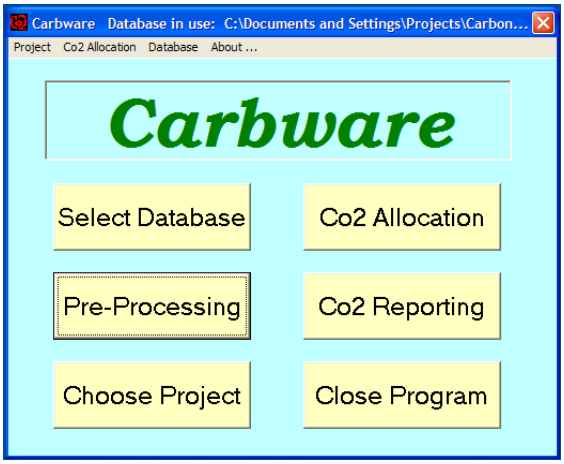
  e.g. C:\Documents and Settings\Projects\Carbon_Project\Carbwini2005.db



Important: Always remember to work with a copy of your original MS Access inventory database file as the CARBWARE pre-processing function will modify the tables in the database and original database formats will be lost.

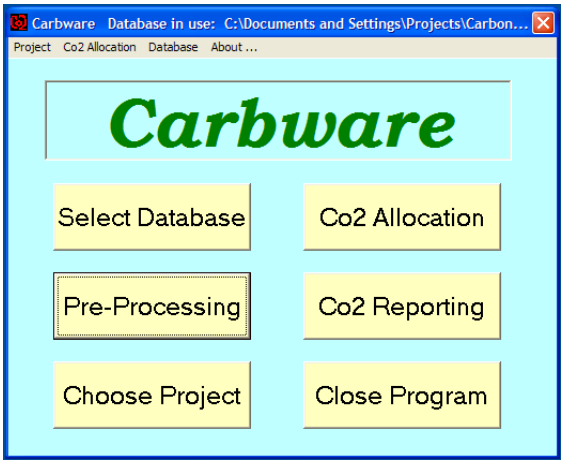
Note: Only MS Access database files named with the prefix **Carbw** will be available for selection (see Section 4.1.1 for details).

- When you have selected the required database you will return to the **Main Menu** screen and the selected database will be active and ready for pre-processing.

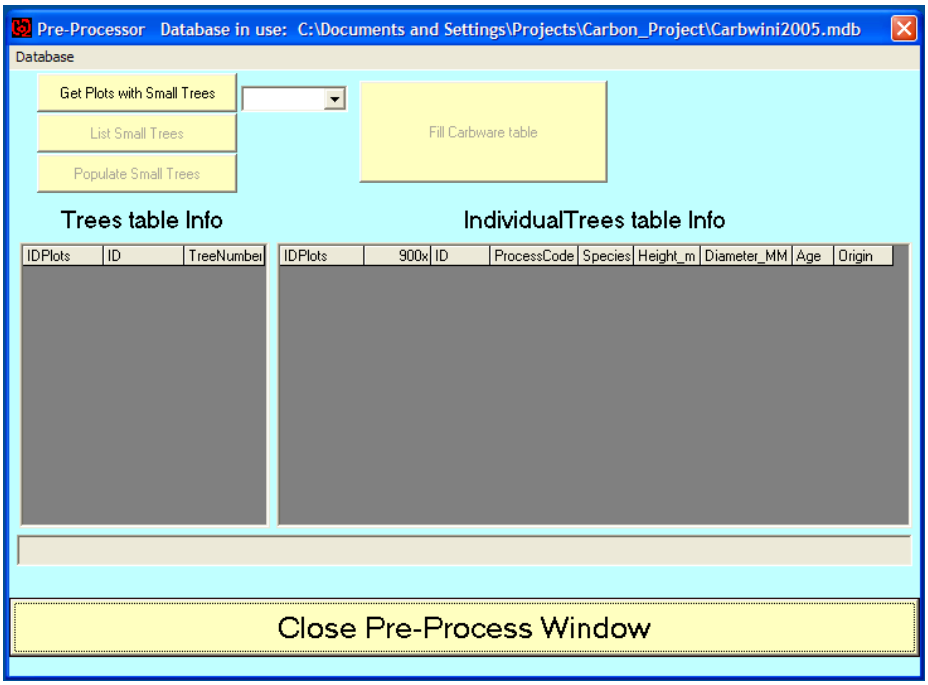


5.2 Populating Trees Table with Small Tree Records from IndividualTrees Table

- With the required database selected (see Section 5.1), click on the **Pre-Processing** button in the **Main Menu** screen:

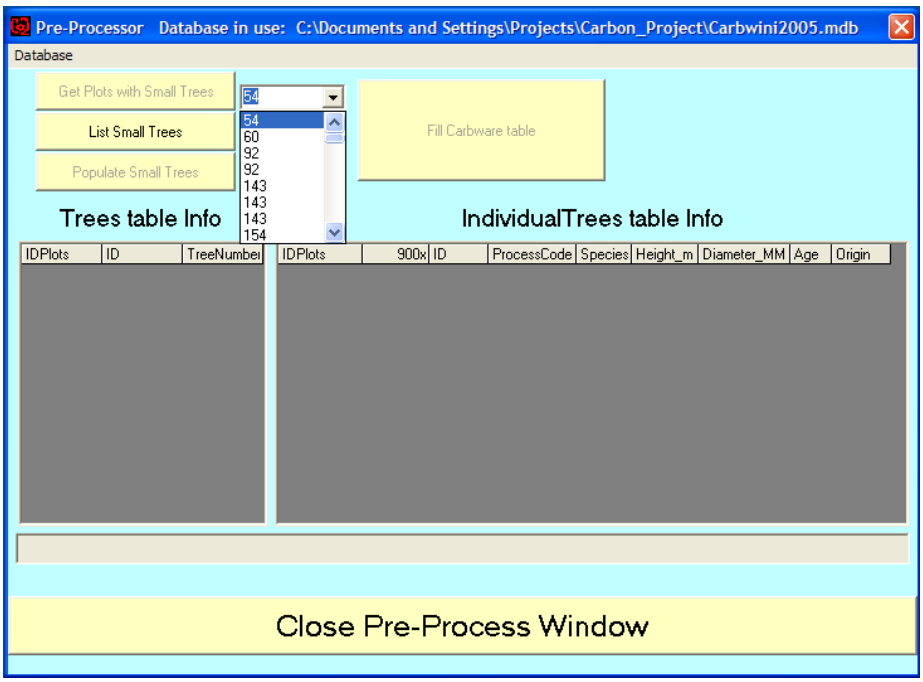


- You will see the following **Pre-Processing** control screen:



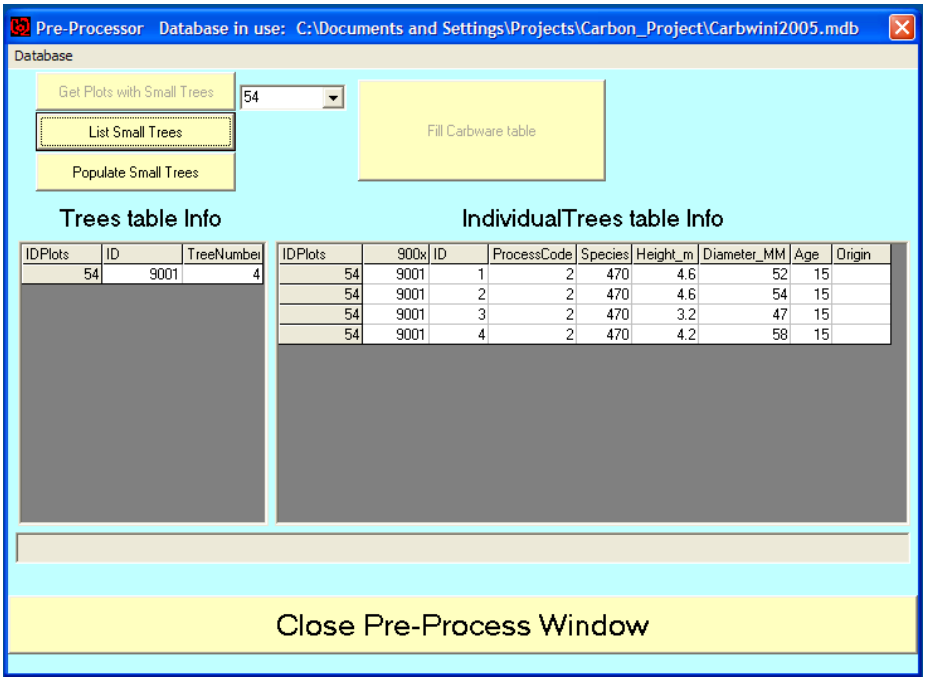
Note: The database in use is always referenced at the top of this screen.

- If you do not wish to proceed with pre-processing your inventory database, click on the **Close Pre-Process Window** button and you will return to the **Main Menu** screen.
- To proceed with pre-processing your inventory database, click on the **Get Plots with Small Trees** button. A drop down listing of all inventory plots with small trees will be shown:



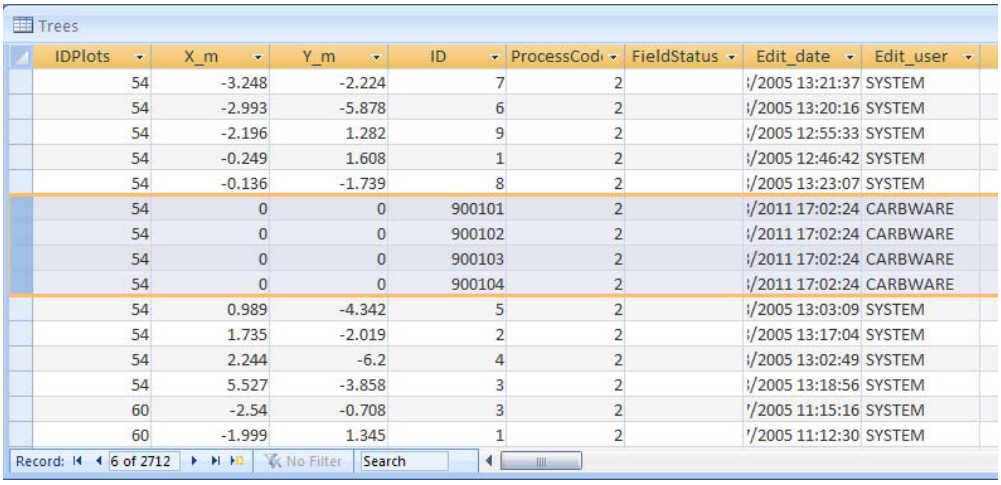
Note: Refer to Section 3.2 for a detailed description of the CARBWARE pre-processing module functions that process standardised inventory data into a format that can be used by the CARBWARE growth and modification models.

- The user must repeat a routine of listing and then populating the Small Trees within each selected plot. This is done as follows:
- Select a Plot using the Drop Down Box. In this example Plot 54 is selected.
- Click on the **List Small Trees** button. All small trees within Plot 54 will be listed. In this example there are 4 small trees.


Pre-Processor Database in use: C:\Documents and Settings\Projects\Carbon_Project\Carbwini2005.mdb
Database
Get Plots with Small Trees
54
List Small Trees
Populate Small Trees
Fill Carbware table
Trees table Info
IndividualTrees table Info
IDPlots ID TreeNumber
54 9001 4
IDPlots 900x ID ProcessCode Species Height_m Diameter_MM Age Origin
54 9001 1 2 470 4.6 52 15
54 9001 2 2 470 4.6 54 15
54 9001 3 2 470 3.2 47 15
54 9001 4 2 470 4.2 58 15
Close Pre-Process Window

- Click on the **Populate Small Trees** button. All small trees within the selected plot will be added to the **Trees Table** within your inventory database. In this example there are 4 small trees within Plot 54, and 4 new records will be added to the Trees Table.

Note: Results of this pre-processing routine can be seen in the **Trees Table** within your inventory database in the form of new records. In this example (see below) the processing of small trees in plot 54 has resulted in 4 new records being created in the Trees Table. Newly created records for small trees will always have an ID beginning with 9001 and "CARBWARE" will always be assigned to the Edit_user field to identify the fact that the Trees Table has been modified by the CARBWARE pre-processing module.



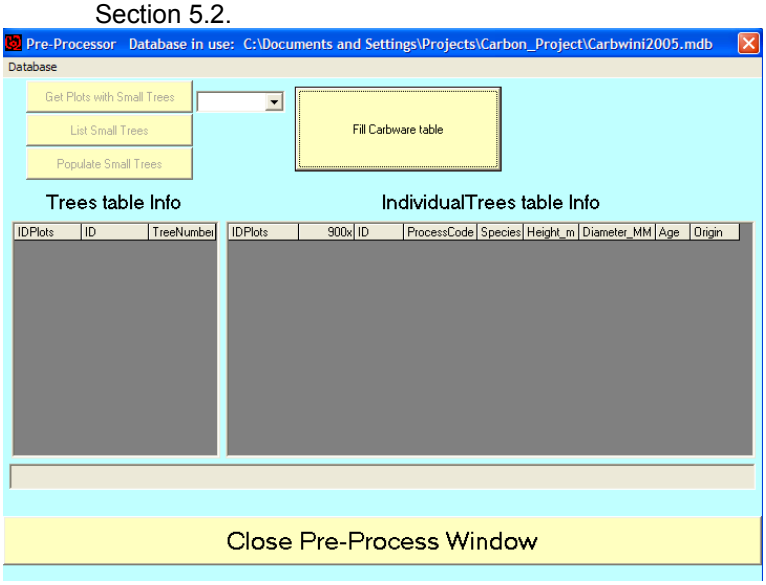
- As each plot with small trees is successfully pre-processed, it will be removed from the drop down listing of inventory plots with small trees. The user must repeat the routine of listing and then populating the Small Trees within each plot until all inventory plots with small trees have been

pre-processed and no more plots are listed. The inventory database in now ready to create the Carbware Table which will form the basis of all growth simulation, stand modification and carbon allocation routines to be performed on the inventory database (see Section 5.3).

5.3 Creating the Carbware Table

- Once all Small Trees have been populated into the Trees Table (see Section 5.2), click on the **Fill Carbware table** button in the **Pre-Processing** control screen.

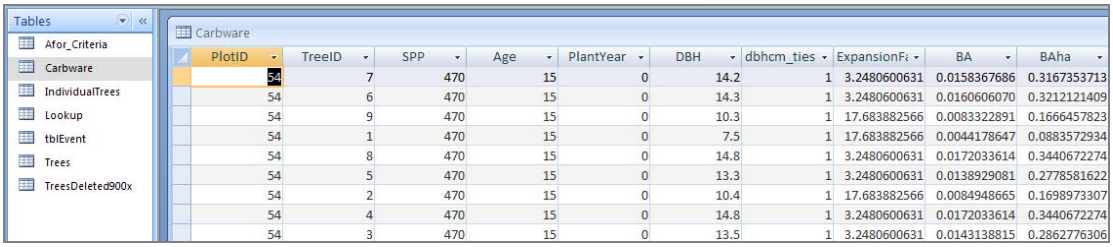
Note: The **Fill Carbware table** button will remain deactivated until all Small Trees have been populated into the Trees Table using the pre-processing routine outlined in Section 5.2.



- The final stage of the pre-processing routine will begin and a status / progress bar will appear. The time taken to perform this pre-processing will depend on the size of your inventory database. When the pre-processing routine is complete you will see the message “Pre-Processing completed”. Click on the **Close Pre-Process Window** button and you will return to the **Main Menu** screen

Note: Once complete, results of this pre-processing routine can be seen in the populated **Carbware Table** within your inventory database. The Carbware Table forms the basis of all growth simulation, stand modification and carbon allocation routines to be performed on the inventory database. It contains many new calculated fields which are described in Table 3 below.

Refer to Section 3.2 for a description of the CARBWARE pre-processing functionality resulting in the Carbware Table.



PlotID	TreeID	SPP	Age	PlantYear	DBH	dbhcm_ties	ExpansionFa	BA	BAha
54	7	470	15	0	14.2	1	3.2480600631	0.0158367686	0.3167353713
54	6	470	15	0	14.3	1	3.2480600631	0.0160606070	0.3212121409
54	9	470	15	0	10.3	1	17.683882566	0.0083322891	0.1666457823
54	1	470	15	0	7.5	1	17.683882566	0.0044178647	0.0883572934
54	8	470	15	0	14.8	1	3.2480600631	0.0172033614	0.3440672274
54	5	470	15	0	13.3	1	3.2480600631	0.0138929081	0.2778581622
54	2	470	15	0	10.4	1	17.683882566	0.0084948665	0.1698973307
54	4	470	15	0	14.8	1	3.2480600631	0.0172033614	0.3440672274
54	3	470	15	0	13.5	1	3.2480600631	0.0143138815	0.2862776306

Field Code	Description
PlotID	Plot ID
TreeID	Tree ID
SPP	Species look up ID (see **ID** field in look up file on instillation disc file name: **model_cohort_lookup.xls**)
Age	Age of tree
PlantYear	Year planted
DBH	Diameter at breast height (1.3 m) in cm
dbhcm_ties	Calculated parameter showing values with the same DBH (indicated as '2')
ExpansionFactor	Representative number of trees (see Information Box 1)
BA	Calculated basal area of tree in m^2
BAha	Calculated basal area of tree per ha (form DBH and plot area)
Density	Calculated Tree per ha
RepreBA	Calculated BAha * Expansion factor
BAL	Sum of all RepreBA in a plot smaller than object tree
BAL_ties_adjusted3	Adjusted BAL to account identical DBH values
HT	Measured H from Trees and individual trees tables
CalcHeight_m	NFI generalised DBH H estimate from Trees table
Estim_Ht	Calculated H using individual tree models
Logit_CR	Log of Crown ratio
CR_Invent	Measured crown ration (999 is null)
CR_Calc	Calculated crown ratio
OGCD	Calculated max radius threshold for open grown tree
OGCA	Calculated max diameter threshold for open grown tree
EP_OGCA	Adjusted competition factor for partial sample
CCF	Calculated crown competition factor
lnCCF	Ln (CFF)
DBH_Increment	Calculated DBH increment
HT_Increment	Calculated H increment for larger trees
Cohort_Code	Species COHORT ID (see **ID** field in look up file on instillation disc file name: **model_cohort_lookup.xls**)From
Mean_H	Mean H of small trees

H_Index	H index (H/meanH) small trees
plotba_m2_ha	Plot basal area
Pred_H_inc	Predicted H increment for small trees
Adj_Ht	Adjusted value for small tree H increment
Adj_Ht_Err	Erorr note 0 = no error
DeadTree	Dead tree flag (100 alive, 200 recently dead, 300 dead)
logit_pmort	Mortality algorithm
pmort	Probability of tree dying
Weight	Weight factor used for mortality probability

Table 3 – Description of Carbware Table Fields

6 Creating or Selecting a Carbware Project

6.1 Creating a New Carbware Project

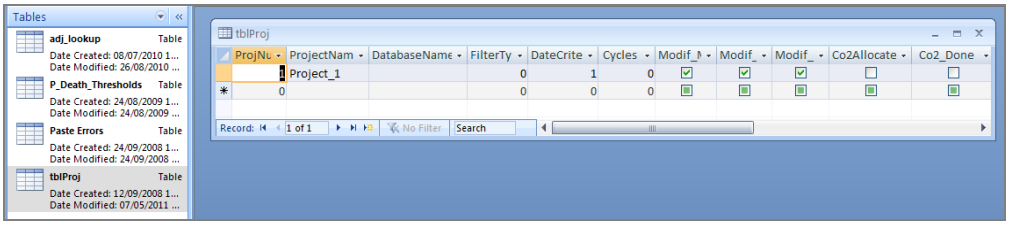
- Once you have pre-processed your inventory database you can now create a CARBWARE project. A project sets the parameters for Growth Simulation and Stand Modification routines to be performed on your inventory database prior to running the Carbon Allocation Process (see Section 9). The following parameters can be set:

  a. The **Forest Inventory Database** to be used. This must be pre-processed as per procedures outlined in Section 5;

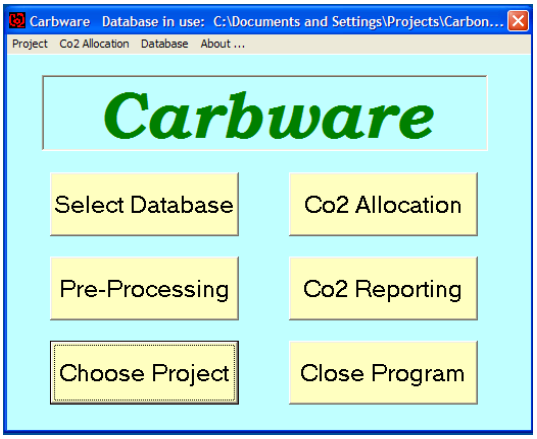
  b. The **range of inventory plots** to be analysed within the selected Inventory Database. All or a sub-set of inventory plots can be selected based on user defined Plot Number Selection or Date Criteria Selection;

  c. The **Stand Modification routines** to be performed on the selected inventory plots.

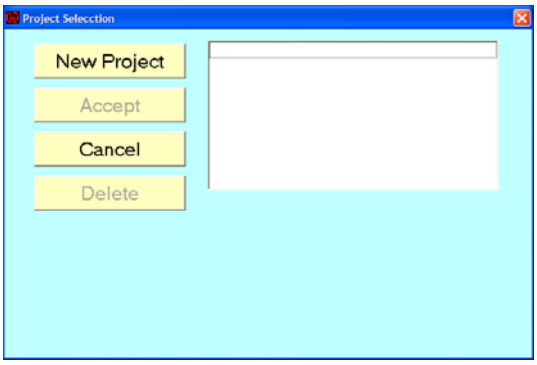
Note: Selected parameters for each new CARBWARE project are stored in the **tblProj** Table located in the **_Carbware_Param** database which is installed as part of the CARBWARE installation.



- To create a new CARBWARE project click on the **Choose Project** button in the **Main Menu** screen:

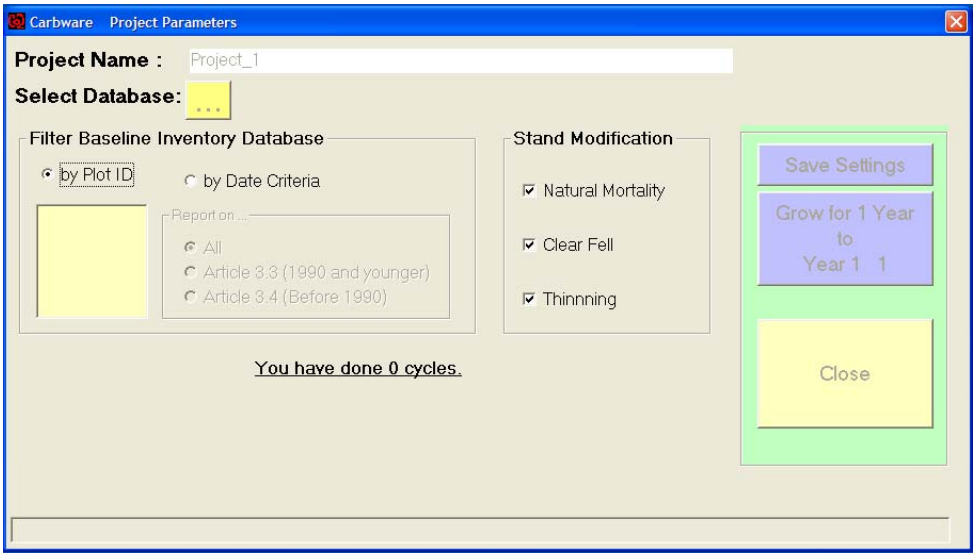


- You will see the following **Project Selection** screen:



Note: If you have already created a CARBWARE project it will be listed on the right hand side of this screen (see Section 6.2 for details on how to select an existing CARBWARE project).

- To return to the **Main Menu** screen without creating or selecting a CARBWARE project click on the **Cancel** button. To proceed with creating a new CARBWARE project click on the **New Project** button. You will see the following **Project Parameters** screen:



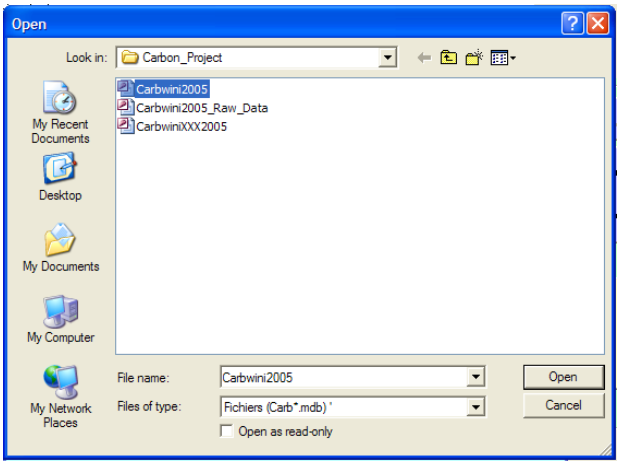
This screen allows you to set the parameters for your CARBWARE project's Growth Simulation and Stand Modification routines and to run annual growth simulation & stand modification cycles for up to 15 years.

- Enter a Project Name (e.g. Project_1).

6.1.1 Selecting the required Forest Inventory Database

- To select the required Forest Inventory Database for your new CARBWARE project click on the **Select Database** button in the **Project Parameters** screen and navigate your PC filing system to locate and open the required inventory database:

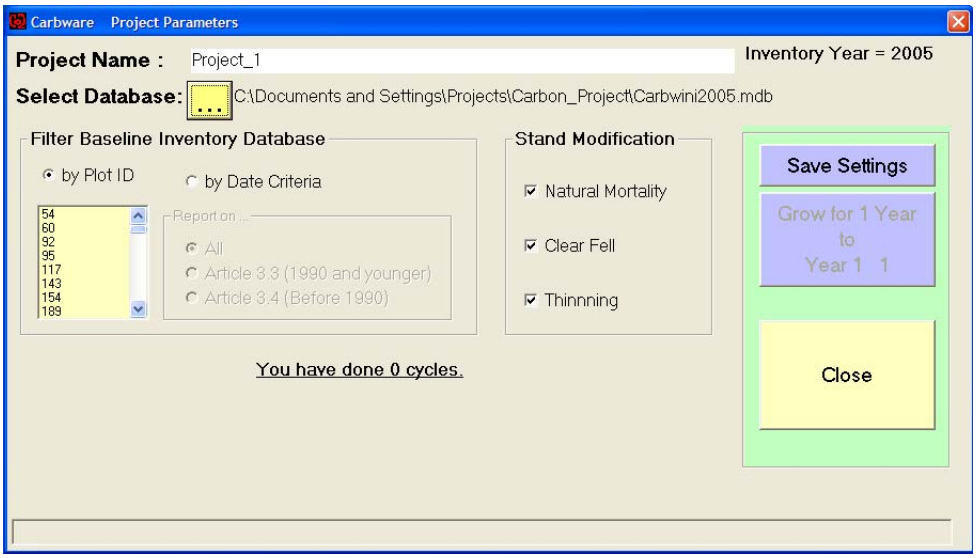
  e.g. C:\Documents and Settings\Projects\Carbon_Project\Carbwini2005.db



Important: You can only work with an inventory database that has been pre-processed. See Section 5 for details on pre-processing your forest inventory data.

- The selected inventory database will be assigned to the CARBWARE project and you will return to the **Project Parameters** screen. The selected inventory database will be shown on this screen below the Project Name and the Inventory Year will be displayed in the top right hand corner.

Note: Inventory Year is determined by the inventory database file naming convention. The last four digits of the inventory database filename determine the Inventory Year for the selected database. Refer to Section 4.1.1 for details on how to name your inventory database files correctly.



6.1.2 Filtering the Forest Inventory Database by Plot or Date Criteria

- Before initiating Growth Simulation and Stand Modification routines you can select all or a sub-set of inventory plots to work with using the **Filter Baseline Inventory Database controls** within the **Project Parameters** screen.

- To select specific plots, click the **by Plot ID** control on the **Project Parameters** screen and highlight the required plots.

- To select all plots or plots within a certain age class, click the **by Date Criteria** control on the **Project Parameters** screen and highlight the required date criteria: These are identified from the *Afor_Criteria table (an essential prerequisite table in database see section 4.1.1.5)*

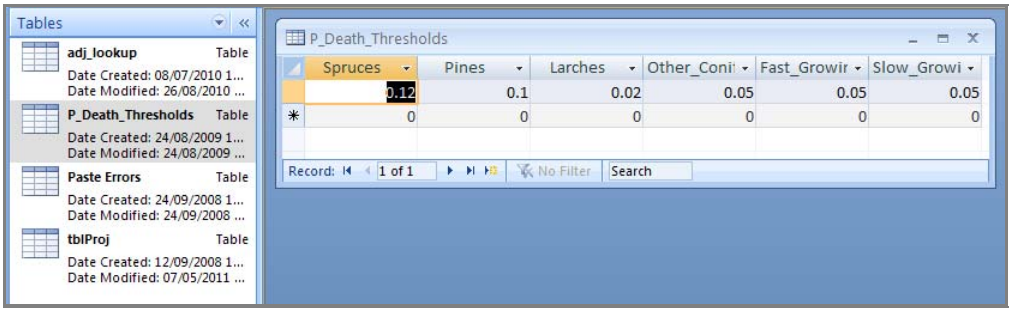
    - **All** will select all inventory plots within the selected forest inventory database;
    - **Article 3.3** will select all trees within the selected forest inventory database that have a planting year of 1990 or younger;
    - **Article 3.4** will select all trees within the selected forest inventory database that have a planting year before 1990.

6.1.3 Selecting the required Stand Modification Events

- Before initiating Growth Simulation and Stand Modification routines you can select whether or not to apply all or some stand modification events using the **Stand Modification controls** within the **Project Parameters** screen. Click on the Tick Box controls next to **Natural Mortality**, **Clear Fell** and **Thinning** to activate or deactivate these stand modification events for your CARBWARE project.

If **Natural Mortality** is activated the CARBWARE model will perform annual mortality events during each annual growth simulation cycle as described in Section 3.2. The species cohort specific probability threshold values used in CARBWARE's natural mortality model can

be defined by the user in the **P_Death_Thresholds** table located in the **_Carbware_Param** database which is installed as part of the CARBWARE installation.



If **Clear Fell** and / or **Thinning** are activated the CARBWARE model will perform clearfell events and / or thinning events after each annual growth simulation cycle as described in Section 3.2. Activated clearfell and thinning events are determined by the **tblEvent** table located in the selected inventory database. All plots (**PlotID**) with a prescribed harvest event (clearfell and / or thinning) must be listed in this table, along with the **Year** of the event, the **Event** code (100 = Clearfell; 200 = Thinning) and the basal area **Reduction** factor (refer to Section 4.1.1.4 for details relating to the **tblEvent** table).

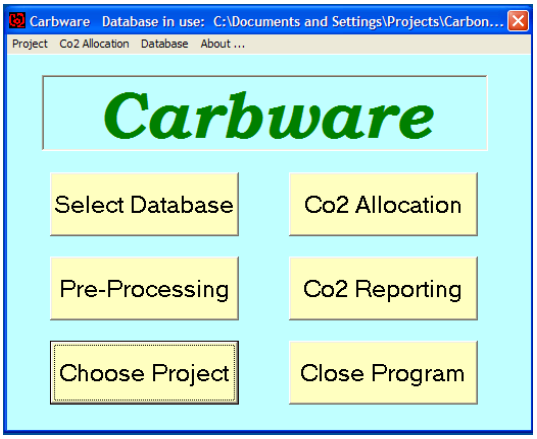
6.1.4 Saving a New Carbware Project

- Once you have set all of the required parameters for your new CARBWARE project you must save the set parameters by clicking the **Save Settings** button on the **Project Parameters** screen.

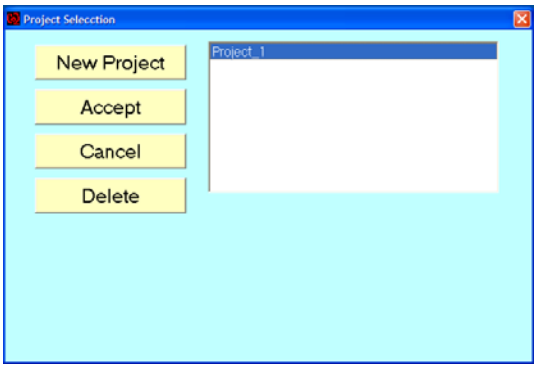
- You can now begin annual Growth Simulation and Stand Modification routines (see Section 7) or return to the **Main Menu** screen by clicking the **Close** button on the **Project Parameters** screen.

6.2 Selecting a Saved Carbware Project

- To select and open a saved CARBWARE project click on the **Choose Project** button in the **Main Menu** screen:



- You will see the following **Project Selection** screen:



Note: All previously saved CARBWARE projects (that have not yet been deleted) will be listed on the right hand side of this screen.

- To return to the **Main Menu** screen without selecting a CARBWARE project click on the **Cancel** button. To select a CARBWARE project click on one of the Project Names listed on the right hand side of this screen and then click on the **Accept** button. The **Project Parameters / Growth Simulation** screen will open and the saved parameters associated with the selected CARBWARE project will be displayed.

- You are now ready to perform annual Growth Simulation (and Stand Modification) routines on your selected inventory database (see Section 7).

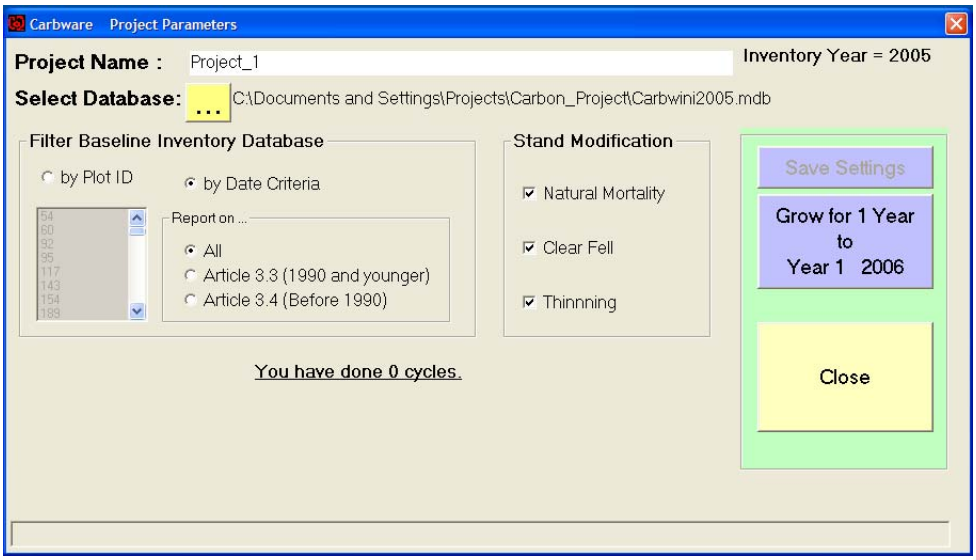
Note: To delete an existing CARBWARE project listed on the right hand side of this screen, click on the project name (it will become highlighted) and then click on the Delete button.

7 Growth Simulation

7.1 Running Annual Growth Cycles

- Following guidelines outlined in Section 6, select and open the required CARBWARE project.

- You will see the following **Project Parameters** screen, with the saved parameters associated with your project.



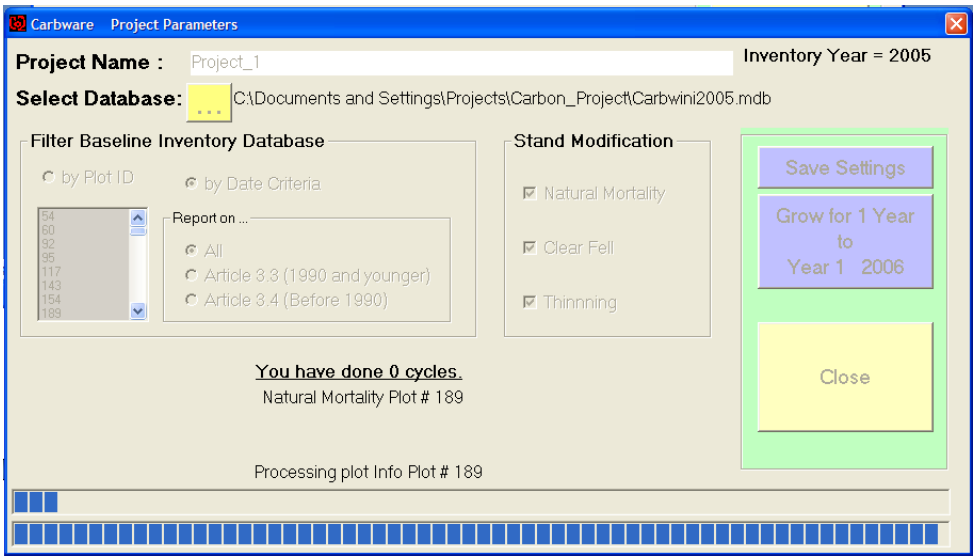
Note: The following parameters are associated with this project:

Project Name:	Project_1
Forest Inventory Database:	Carbwini2005.mdb
Inventory Year:	2005 (as per Forest Inventory Database naming convention)
Inventory Database Filter:	All plots selected
Stand Modification Options:	Natural Mortality, Clearfell & Thinning Selected

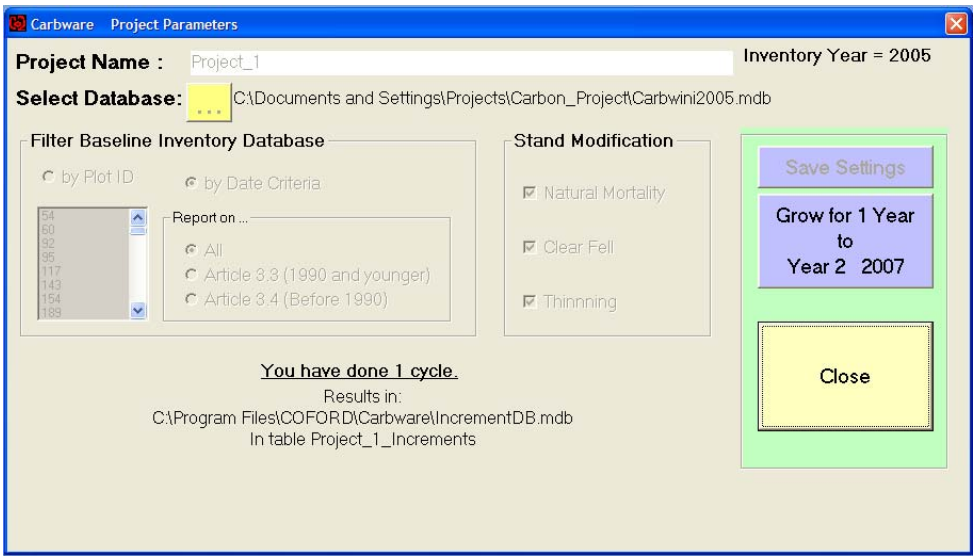
- The number of annual growth cycles performed to date will be noted at the bottom of the **Project Parameters** screen. In this example, 0 cycles have been performed. Up to 15 annual growth cycles can be performed.

- Click on the **Grow for 1 Year** button to perform the first annual growth cycle. CARBWARE will begin an annual growth cycle, performing a complex series of growth modelling and stand modification events as described in Section 3.

Note: The length of time for CARBWARE to complete an annual growth cycle will largely depend on the size of your Forest Inventory Database (number of plots). A large database such as that associated with Ireland's National Forest Inventory will take several hours to process. The **Project Parameters** screen displays a progress bar during an annual growth cycle, informing the user of progress and noting each of the stand modification events as they are simulated (Natural Mortality, Clearfell & Thinning).



- When the first annual growth cycle is completed, a message will be displayed at the bottom of the **Project Parameters** screen noting the number of annual growth cycles performed to date and the location of the results of the latest growth cycle.



Note: Results of annual growth cycles for all CARBWARE projects are stored in the database file **IncrementsDB.mdb** which is installed on your PC as part of the CARBWARE software installation process (see Section 2.3). A series of new tables are created for each of the annual growth cycles. These are described in Section 7.2 below.

- To perform another growth cycle, click on the **Grow for 1 Year** button again.

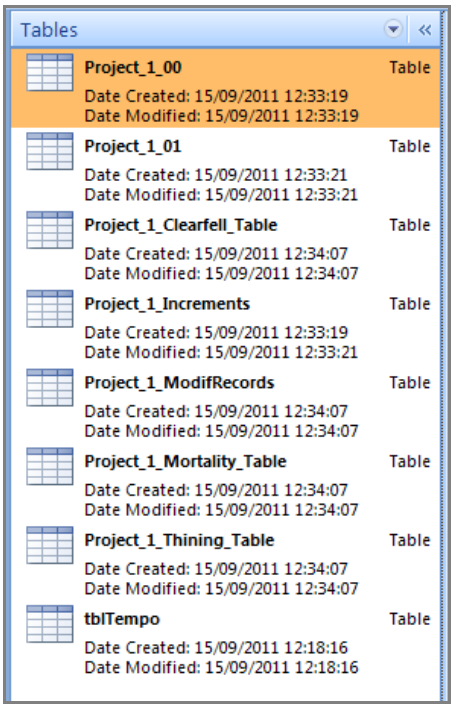
Note: As each annual growth cycle is completed, the **Grow for 1 Year** button is modified to inform the user of the cycle number and the date the next growth cycle will run to. In this example (above) the button reads "**Grow for 1 Year to Year 2 2007**".

- To return to the **Main Menu** screen without performing another growth cycle click on the **Close** button.

Note: You can return to the **Project Parameters** screen to perform additional annual growth cycles at any time.

7.2 Increment Database

- As noted in Section 7.1 above, results of annual growth cycles for all CARBWARE projects are stored in the database file **IncrementsDB.mdb** which is installed on your PC as part of the CARBWARE software installation process (see Section 2.3). A series of new tables are created for each of the annual growth cycles. CARBWARE uses these tables to perform additional annual growth cycles (see Section 7.1) and to perform carbon allocation routines (see Section 9). Tables within the **IncrementsDB.mdb** database file relating to annual growth cycles are described in Sections 7.2.1 and 7.2.2 below. Tables within the **IncrementsDB.mdb** database file relating to stand modification events within the annual growth cycles are described in Section 8.



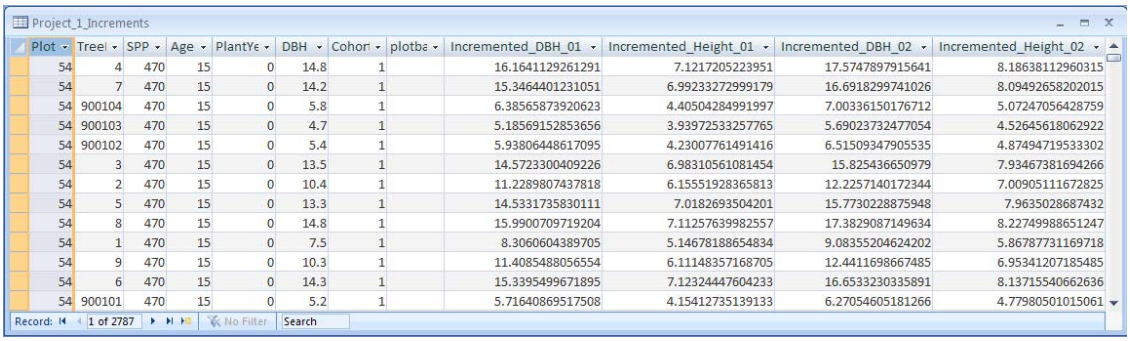
7.2.1 Summary of Annual Growth Cycle Increments (IncrementDB Table)

- An Increments Table will be created for each CARBWARE project that has undergone one or more annual growth cycles. The Increments Table is created and named by CARBWARE using the naming convention **Project Name_Increments** and is stored in the database file **IncrementsDB.mdb**. In this example, the project name is **Project_1** and so the Increments Table is named **Project_1_Increments**.

Important: If you have created several CARBWARE projects, and have run one or more annual growth cycles for each of them, there will be several Increments Tables within your **IncrementsDB.mdb** database and named according to your CARBWARE project names. These tables can be relatively large and may use up significant PC hard disk space. Remember to perform CARBWARE database management routines as outlined in Section 11.

- The Increments Table summarises each of the annual growth cycle DBH and Height increments for each tree within the range of inventory plots included in a CARBWARE project. In the example below, the inventory database has undergone two simulated annual growth cycles. The Increments Table

(**Project_1_Increments**) shows two sets of DBH and Height data. One for the first annual growth cycle (**Incremented_DBH_01**; **Incremented_Height_01**) and one for the second (**Incremented_DBH_02**; **Incremented_Height_02**). If additional annual growth cycles are performed for this project (see Section 7.1), additional sets of DBH and Height data will be computed and recorded in this table.



Project_1_Increments

Plot	Treel	SPP	Age	PlantYe	DBH	Cohort	plotba	Incremented_DBH_01	Incremented_Height_01	Incremented_DBH_02	Incremented_Height_02
54	4	470	15	0	14.8	1		16.1641129261291	7.1217205223951	17.5747897915641	8.18638112960315
54	7	470	15	0	14.2	1		15.3464401231051	6.99233272999179	16.6918299741026	8.09492658202015
54	900104	470	15	0	5.8	1		6.38565873920623	4.40504284991997	7.00336150176712	5.07247056428759
54	900103	470	15	0	4.7	1		5.18569152853656	3.93972533257765	5.69023732477054	4.52645618062922
54	900102	470	15	0	5.4	1		5.93806448617095	4.23007761491416	6.51509347905535	4.87494719533302
54	3	470	15	0	13.5	1		14.5723300409226	6.98310561081454	15.825436650979	7.93467381694266
54	2	470	15	0	10.4	1		11.2289807437818	6.15551928365813	12.2257140172344	7.00905111672825
54	5	470	15	0	13.3	1		14.5331735830111	7.0182693504201	15.7730228875948	7.9635028687432
54	8	470	15	0	14.8	1		15.9900709719204	7.11257639982557	17.3829087149634	8.22749988651247
54	1	470	15	0	7.5	1		8.3060604389705	5.14678188654834	9.08355204624202	5.86787731169718
54	9	470	15	0	10.3	1		11.4085488056554	6.11148357168705	12.4411698667485	6.95341207185485
54	6	470	15	0	14.3	1		15.3395499671895	7.12324447604233	16.6533230335891	8.13715540662636
54	900101	470	15	0	5.2	1		5.71640869517508	4.15412735139133	6.27054605181266	4.77980501015061

Record: 1 of 2787 No Filter Search

7.2.2 Carbware Tables for each Annual Growth Cycle

- As noted in Section 5.3, the Carbware Table forms the basis of all growth simulation, stand modification and carbon allocation routines to be performed on the inventory database. While the original Carbware Table associated with a CARBWARE project remains in the selected inventory database, an adapted copy of it is created in the **IncrementsDB.mdb** database file for use in annual growth cycle simulations. This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_AnnualGrowthCycleNumber**. In this example, the project name is **Project_1** and so the first project specific CARBWARE Table is named **Project_1_00**.

- **Project_1_00** represents an adapted copy of the project's inventory database Carbware Table at time 0, prior to any annual growth cycle simulations. This is the baseline data used by the CARBWARE model for growth simulation and stand modification event simulation from Year 0 (the inventory year) to Year 1 (the inventory year +1). While this table is very similar to the project's original inventory database Carbware Table, there are some additional fields required for Carbon Allocation purposes which are described in Table 4 below.

Field Code	Description	Unit
CF_TH	redundant	
AG	Above ground biomass	Kg C per tree
TB	Total biomass	Kg C per tree
NB	Needle/leaf biomass	Kg C per tree
LTR	Litter fall rate	Kg C per tree
SB	Stem biomass	Kg C per tree
RB	Root biomass	Kg C per tree
LT	Lop and top biomass	Kg C per tree
Adj_AB_dead	Adjusted dead biomass (Standing dead * Exp factor)	Kg C
Adj_AB_live	Adjusted live abovegroung biomass (Standing dead * Exp factor)	Kg C
Litterfall	Adjusted littefall (LTR* Exp factor)	Kg C
SB_C	Adjusted Stembiomass (SB * Exp factor)	Kg C
Dead_RB	Adjusted dead root biomass (DeadRB * Exp factor)	Kg C
RB_C	Adjusted root biomass (RB * Exp factor)	Kg C

deadLT	Dead lop and top (	Kg C
LT_C	Adjusted dead biomass (Standing dead * Exp factor)	
Standing_Dead_T0	Adjusted dead biomass (Standing dead * Exp factor)	

Table 4 – Description of additional Carbware Table Fields in the IncrementsDB.mdb database

- **Project_1_01** represents an updated version of the project's Carbware Table (**Project_1_00)** following one annual growth cycle simulation, including Height & DBH growth and the results of any stand modification events prescribed by the **tblEvent** Table located in the selected inventory database. This is now the baseline data used by the CARBWARE model for growth simulation and stand modification event simulation from Year 1 (the inventory year +1) to Year 2 (the inventory year +2) etc. For any project there can be up to 16 intermediate Carbware Tables (Year 0 to Year 15).

  Note: Any records (trees) that have been removed due to stand modification events during the first annual growth cycle simulation will no longer be listed in this table. Instead, they will be listed in one of the Stand Modification Events tables (see Section 8).

- As well as being used for annual growth cycle simulations, these intermediate Carbware Tables are used for Carbon Allocation purposes (see Section 9).

8 Stand Modification

8.1 Stand Modification Events during Annual Growth Cycles

- As described in Sections 4.1.1.4 and 6.1.3, a series of prescribed stand modification routines can be performed on your inventory database plots during annual growth cycles, determined by your project's parameter settings (see Section 6.1) and the modification events (Thinning & Clearfell) prescribed in the **tblEvent** table in your project's inventory database.

  Note: Stand modification events include **Natural Mortality**, **Thinning** and **Clearfelling**. It is not mandatory to run all or any stand modification events as part of your CARBWARE project. You can turn events on or off using the Project Parameter controls when creating a new CARBWARE project (see Section 6.1.3).

- As noted in Section 7.1, results of annual growth cycles for all CARBWARE projects are stored in the database file **IncrementsDB.mdb** which is installed on your PC as part of the CARBWARE software installation process (see Section 2.3). A series of new tables are created for each of the annual growth cycles. CARBWARE uses these tables to perform additional annual growth cycles (see Section 7.1) and to perform carbon allocation routines (see Section 9). Tables within the **IncrementsDB.mdb** database file relating to annual growth cycles are described in Sections 7.2.1 and 7.2.2 below. Tables within the **IncrementsDB.mdb** database file relating to stand modification events within the annual growth cycles are described in Sections 8.2 below.

8.2 Stand Modification Event Tables

All stand modification events performed on your inventory database plots are recorded in a series of new tables stored in the **IncrementsDB.mdb** database file. These tables are described in Sections 8.2.1 to 8.2.4 below.

8.2.1 Modified Records Table

- The Modified Records Table within the **IncrementsDB.mdb** database file lists all records (trees) within your inventory database plots that have been modified by Natural Mortality, Thinning or Clearfell events during annual growth cycles.

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_ModifRecords**. In this example, the project name is **Project_1** and so the project specific Modified Records Table is named **Project_1_ModifRecords**.

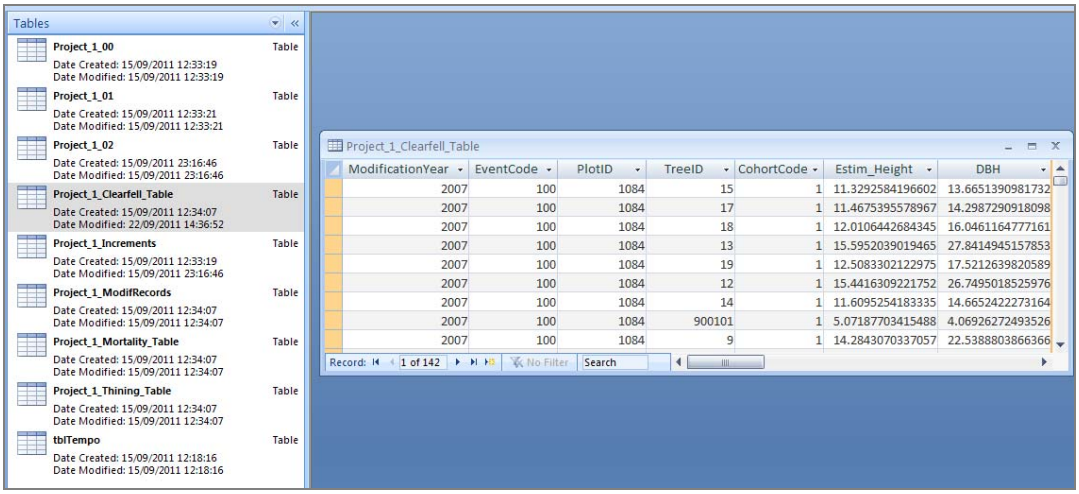
- The **CF_TH field** in this table notes the stand modification event type that has modified a record (tree). This can be **100 (Clearfell)**, **200 (Thinning)** or **300 (Natural Mortality)**.

8.2.2 Clearfell Events Table

- The Clearfell Events Table within the **IncrementsDB.mdb** database file lists all records (trees) within your inventory database plots that have been clearfelled during annual growth cycles.

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_Clearfell_Table**. In this example, the project name is **Project_1** and so the project specific Clearfell Events Table is named **Project_1_ Clearfell_Table**. This events table lists all of the trees within your inventory database that have been clearfelled during any of your CARBWARE project's annual growth cycles. In this example there have been two annual growth cycles for Project_1 (2005 to 2006 and 2006 to 2007), noted by the fact that there are three Carbware Tables (Project_1_00, Project_1_01 and Project_1_02. The year of each clearfell event is noted in the **ModificationYear field** in this table. The EventCode field notes the stand modification event type that has modified a record (tree). This will always be **100 (Clearfell)**.

- In this example, there has been a total of 142 trees clearfelled over the two annual growth cycles for Project_1. All of the events were in 2007 and 4 Plots were modified.



- The Clearfell Events Table contains all of the necessary information for performing annual Carbon Allocation routines on the results of annual growth and stand modification simulations specific to prescribed clearfell events. The Clearfell Events Table fields are described in Table 5 below.

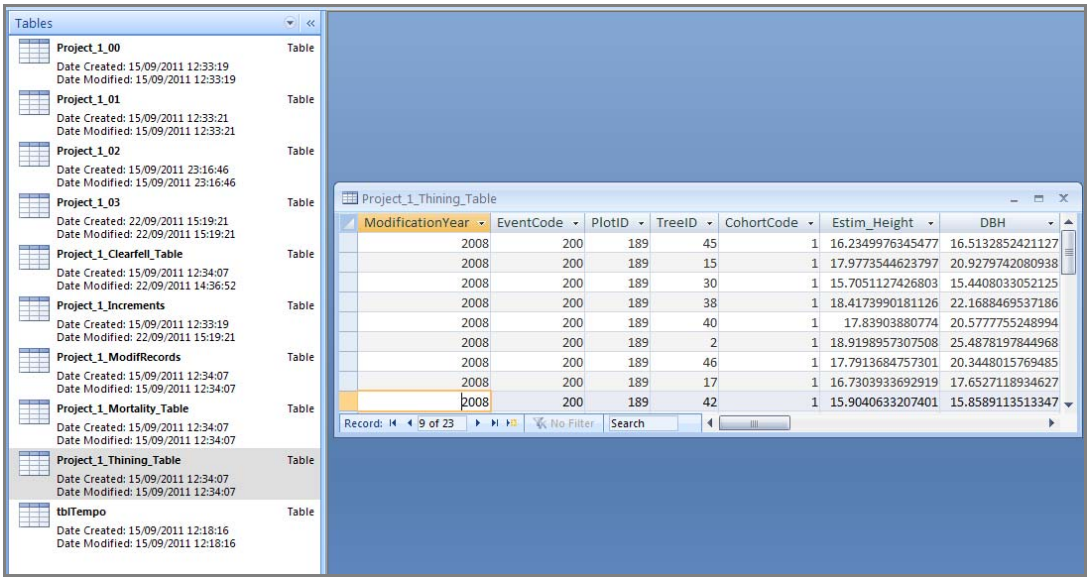
Field Code	Description	Unit

ModificationYear	Year of Clearfell	None
EventCode	Code 100 = clearfell	None
PlotID	Plot ID number	None
TreeID	Tree ID harvested	None
CohortCode	Cohort see cohort look up	None
Estim_Height	Height estimated	m
DBH	Diameter at breast height	cm
Age	Age of harvested tree	years
ExpansionFactor	Expansion factor for partial sample plot	None
DeadTree	tree status 100=alive, 200 = dead	None
AG	Aboveground biomass	kg C
TB	Total biomass	kg C
NB	Needle/leaf biomass	kg C
LTR	Harvest stumpage residue	kg C
SB	Stem biomass	kg C
RB	Root biomass	kg C
LT	lop and top	kg C
AB_C	representative AG biomass (AG*Exp factor)	kg C
SB_C	representative SB biomass (SB*Exp factor)	kg C
RB_C	representative RB biomass (RB*Exp factor)	kg C
LT_C	representative LT biomass (LT*Exp factor)	kg C
Volume	representative tree volume	m3

Table 5 – Description of Clearfell Events Table Fields in the IncrementsDB.mdb database

8.2.3 Thinning Events Table

- The Thinning Events Table within the **IncrementsDB.mdb** database file lists all records (trees) within your inventory database plots that have been thinned during annual growth cycles.
- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_Thinning_Table**. In this example, the project name is **Project_1** and so the project specific Thinning Events Table is named **Project_1_ Thinning_Table**. This events table lists all of the trees within your inventory database that have been thinned during any of your CARBWARE project's annual growth cycles. In this example there have been three annual growth cycles for Project_1 (2005 to 2006, 2006 to 2007 and 2007 to 2008), noted by the fact that there are four Carbware Tables (Project_1_00, Project_1_01, Project_1_02 and Project_1_03. The year of each thinning event is noted in the **ModificationYear field** in this table. The EventCode field notes the stand modification event type that has modified a record (tree). This will always be **200 (Thinning)**.
- In this example, there has been a total of 23 trees thinned over the three annual growth cycles for Project_1. All of the events were in 2008 and only 1 Plot was modified.



- The Thinning Events Table contains all of the necessary information for performing annual Carbon Allocation routines on the results of annual growth and stand modification simulations specific to prescribed thinning events. The Thinning Events Table fields are described in Table 6

Field Code	Description	Unit
ModificationYear	Year of Thinning	None
EventCode	Code 200 = thinning	None
PlotID	Plot ID number	None
TreeID	Tree ID harvested	None
CohortCode	Cohort see cohort look up	None
Estim_Height	Height estimated	m
DBH	Diameter at breast height	cm
Age	Age of harvested tree	years
ExpansionFactor	Expansion factor for partial sample plot	None
DeadTree	tree status 100=alive, 200 = dead	None
AG	Aboveground biomass	kg C
TB	Total biomass	kg C
NB	Needle/leaf biomass	kg C
LTR	Harvest stumpage residue	kg C
SB	Stem biomass	kg C
RB	Root biomass	kg C
LT	lop and top	kg C
AB_C	representative AG biomass (AG*Exp factor)	kg C
SB_C	representative SB biomass (SB*Exp factor)	kg C
RB_C	representative RB biomass (RB*Exp factor)	kg C
LT_C	representative LT biomass (LT*Exp factor)	kg C
Volume	represenatrive tree volume	m3

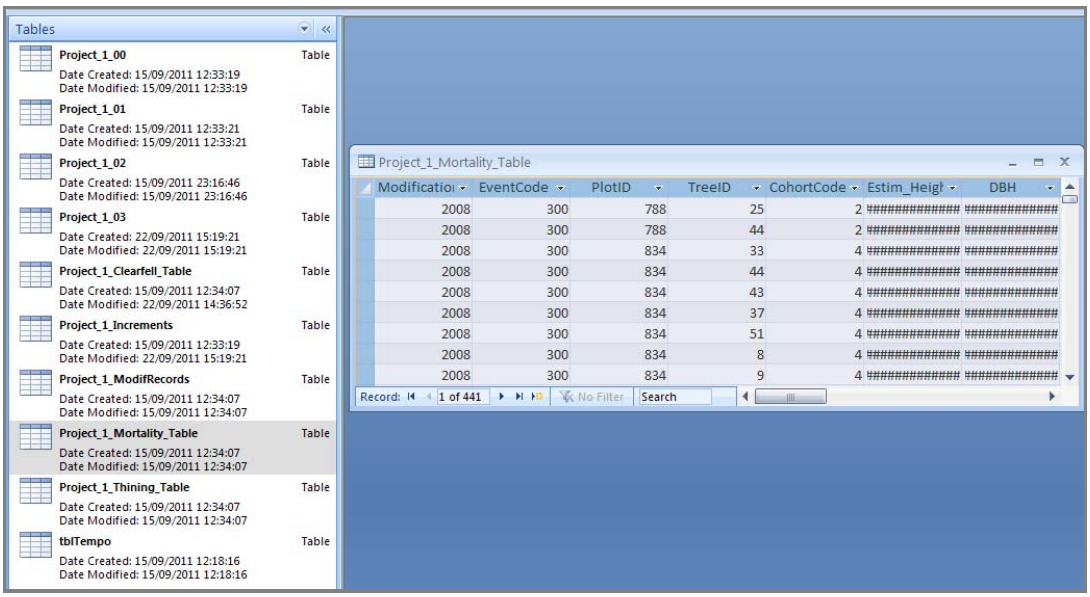
Table 6 – Description of Thinning Events Table Fields in the IncrementsDB.mdb database

8.2.3 Mortality Events Table

- The Mortality Events Table within the **IncrementsDB.mdb** database file lists all records (trees) within your inventory database plots that have died as a result of the CARBWARE natural mortality function during annual growth cycles.

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_Mortality_Table**. In this example, the project name is **Project_1** and so the project specific Mortality Events Table is named **Project_1_ Mortality_Table**. This events table lists all of the trees within your inventory database that have died during any of your CARBWARE project's annual growth cycles. In this example there have been three annual growth cycles for Project_1 (2005 to 2006, 2006 to 2007 and 2007 to 2008), noted by the fact that there are four Carbware Tables (Project_1_00, Project_1_01, Project_1_02 and Project_1_03. The year of each mortality event is noted in the **ModificationYear field** in this table. The EventCode field notes the stand modification event type that has modified a record (tree). This will always be **300 (Natural Mortality)**.

- In this example, a total of 441 trees have died over the three annual growth cycles for Project_1. Mortality events were in 2006, 2007 and 2008.



- The Mortality Events Table contains all of the necessary information for performing annual Carbon Allocation routines on the results of annual growth and stand modification simulations specific to prescribed thinning events. The Mortality Events Table fields are exactly the same as the Clearfell Events Table fields described in Table 6 (see Section 8.2.2), with one exception. The final field is named **standing_deadwood** and replaces the **Volume field** in the Clearfell Events Table and Thinning Events Table (see Table 7 below).

Field Code	Description	Unit
ModificationYear	Year of mortality	None
EventCode	Code 300 = mortality	None
PlotID	Plot ID number	None
TreeID	Tree ID dead	None
CohortCode	Cohort see cohort look up	None
Estim_Height	Height estimated	m
DBH	Diameter at breast height	cm
Age	Age of harvested tree	years
ExpansionFactor	Expansion factor for partial sample plot	None
DeadTree	tree status 100=alive, 200 = dead, 300 damaged tree	None
AG	Aboveground biomass	kg C
TB	Total biomass	kg C
NB	Needle/leaf biomass	kg C
LTR	Harvest stumpage residue	kg C
SB	Stem biomass	kg C
RB	Root biomass	kg C
LT	lop and top	kg C
AB_C	representative AG biomass (AG*Exp factor)	kg C
SB_C	representative SB biomass (SB*Exp factor)	kg C
RB_C	representative RB biomass (RB*Exp factor)	kg C
LT_C	representative LT biomass (LT*Exp factor)	kg C
Standing deadwood	representative dead tree total biomass	kg C

Table 7 – Description of Mortality Events Table Fields in the IncrementsDB.mdb database

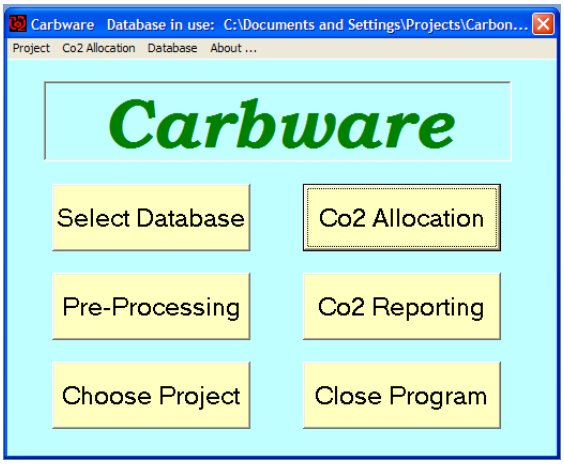
9 Carbon Allocation

Once you have completed the growth and stand modification event simulations for your CARBWARE project, you must complete the Carbon Allocation process before you can generate any CARBWARE results. As described in Section 3.2, the CARBWARE Carbon Allocation process uses the intermediate growth output tables (described in Sections 7 and 8) to generate carbon stock estimates for 6 major carbon pools. These are:

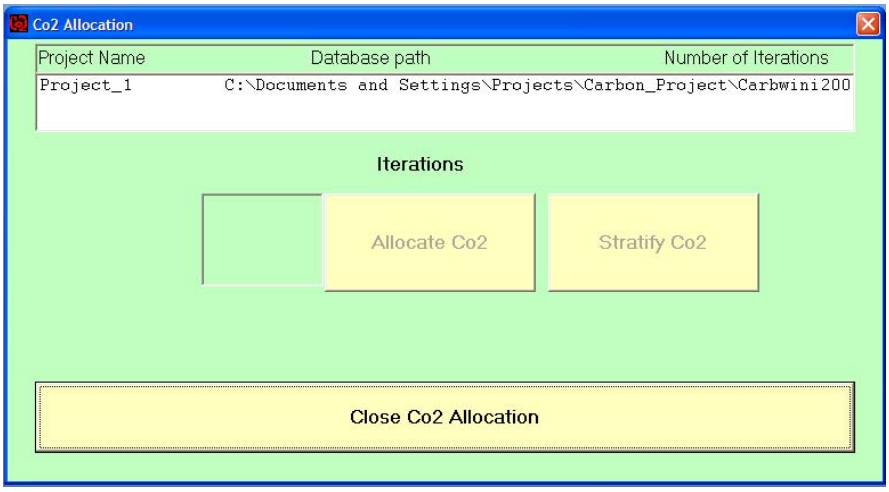
- Above Ground
- Below Ground
- Deadwood
- Litter
- Soil
- Harvested Wood Products

9.1 Running the Carbon Allocation Process

- To run the Carbon Allocation process for a CARBWARE project, click on the **Co2 Allocation** button in the **Main Menu** screen:



- You will see the following **Co2 Allocation** screen:



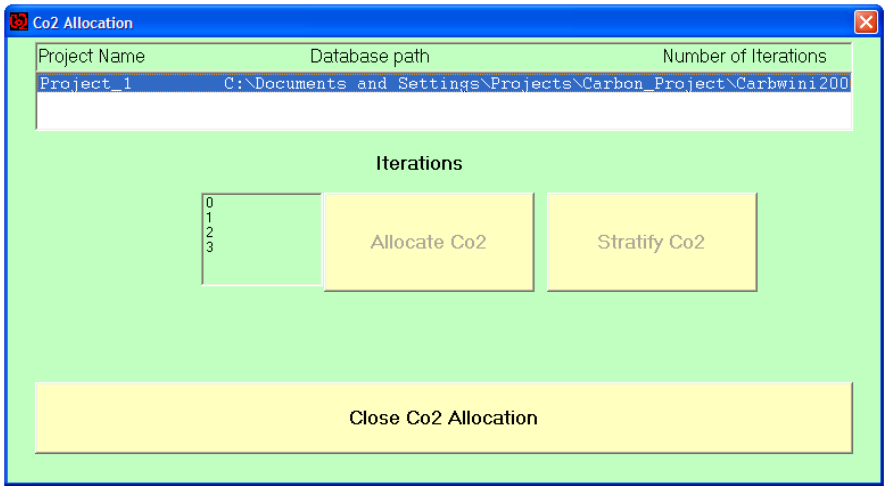
- If you do not wish to proceed with the Carbon Allocation process, click on the **Close Co2 Allocation** button and you will return to the **Main Menu** screen.

- The **Co2 Allocation** screen lists all current CARBWARE projects that have yet to undergo the Carbon Allocation Process. In this example there is only one project (**Project_1**).

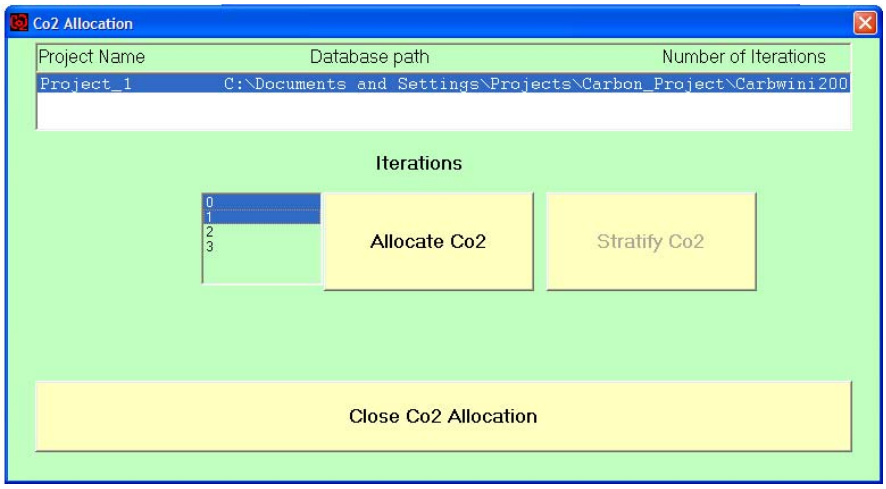
- To proceed with the Carbon Allocation process, select the required project by clicking on the project name. The project name will become highlighted and a list of all annual growth cycles (**Iterations**) will be shown. In this example there have been 3 annual growth cycles and 4 carbon allocations can be performed, one for the baseline inventory year (Year 0) and one for each of the 3 annual growth cycles.

Note: If your CARBWARE project has been run for the maximum of 15 annual growth cycles, 16 carbon allocations can be performed, one for the baseline inventory year (Year 0) and one

for each of the 15 annual growth cycles.

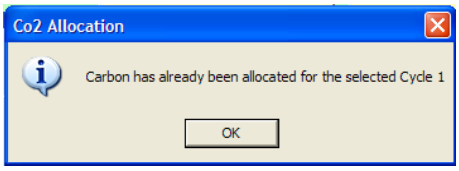


- To proceed with the Carbon Allocation process for one or more of the annual growth cycles performed during the Growth Simulation stage of your CARBWARE project, select one or more of the listed growth cycles. In this example two have been selected, the baseline inventory year (Year 0) and the first annual growth cycles (Year 1). The **Allocate Co2** button will become active.



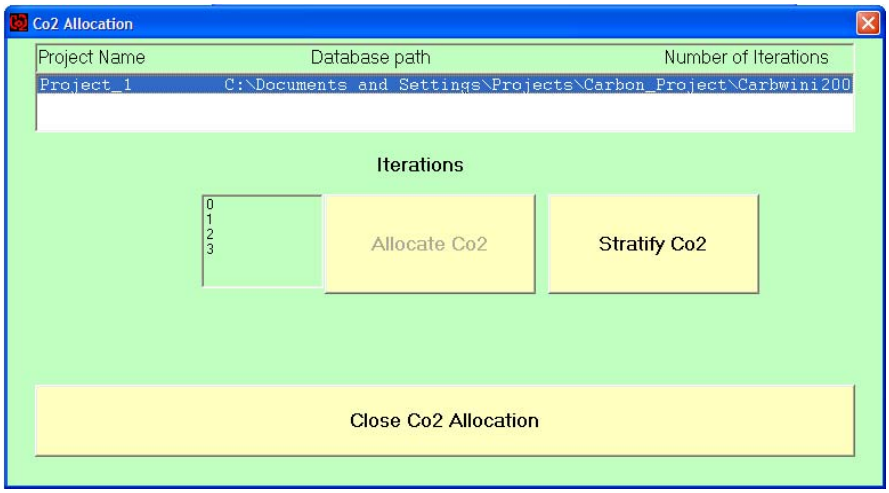
- Click on the **Allocate Co2** button. CARBWARE will perform the Carbon Allocation process for each of the selected growth cycles. Previously unpopulated fields (relating to the six carbon pools) within the project and growth cycle specific CARBWARE Tables in the **IncrementsDB.mdb** database file (see Section 7.2.2) will be populated.

Note: You can run the **Allocate Co2** routine for all or some of the listed growth cycles within your CARBWARE project. If you choose to run the **Allocate Co2** for a sub-set of the listed growth cycles, you can return to the **Co2 Allocation** screen to run the unallocated cycles at a later time. If you attempt to run the **Allocate Co2** routine for growth cycles that have already been allocated, you will see the following Error Message.



- The final stage of the Carbon Allocation process is Carbon Stratification, where CARBWARE stratifies the carbon estimates associated with your forest inventory database into each of the six carbon pools.

- To proceed with the Carbon Stratification process, open the **Co2 Allocation** screen and select the required CARBWARE project. If you have performed the Carbon Allocation process for one or more of your project's growth cycles, the **Stratify Co2** button will be active.



Note: Make sure that you have performed the Carbon Allocation process for each of the project growth cycles you wish to analyse before proceeding with Carbon Stratification.

- Click on the **Stratify Co2** button. CARBWARE will perform the Carbon Stratification process and will create 6 new tables in the **IncrementsDB.mdb** database file (see Section 9.2). These tables are used for all CARBWARE reporting processes (see Section 10).

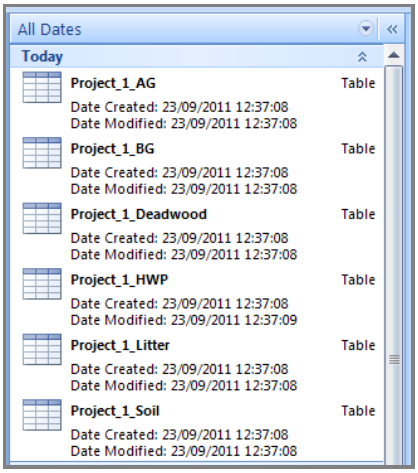
Important: The Carbon Stratification process normalises all inventory plot units to 1 ha by referencing user specified plot sizes recorded in the **Lookup table** located in your CARBWARE project's Forest Inventory Database (e.g. Carbwini2005.db).

Important: Some of the initial carbon pools (at plot level) must be input by the user in the **Lookup table** located in your CARBWARE project's Forest Inventory Database (e.g. Carbwini2005.db). This must be done prior to running the Carbon Stratification process. **Lookup table** inputs include initial litter and deadwood inputs and soils emission factors (see Section 4 for further details).

- When you have completed the Carbon Allocation and Stratification process, click on the **Close Co2 Allocation** button and you will return to the **Main Menu** screen.

9.2 Carbon Allocation Tables

- When the CARBWARE Carbon Allocation and Stratification process is run for a project (see Section 9.1), CARBWARE creates a set of six new project specific tables in the **IncrementsDB.mdb** database file for each of the carbon pools.



- These tables, described in Sections 9.2.1 to 9.2.6 below, summarise pool specific results of inventory plot level carbon estimates.

Note: With the exception of the Soil Table, these Carbon Allocation Tables will contain a variable number of fields, depending on the number of annual growth cycles that have been simulated and allocated within your CARBWARE project. The examples presented in Sections 9.2.1 to 9.2.6 below show Carbon Allocation Tables for a project with two annual growth cycles.

9.2.1 Above Ground Carbon Table

- The Above Ground Carbon Table within the **IncrementsDB.mdb** database file summarises above ground carbon estimates within your inventory database plots for each of the annual growth cycles that have been simulated and allocated within your CARBWARE project.

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_AG**. In this example, the project name is **Project_1** and so the project specific Above Ground Carbon Table is named **Project_1_AG**. This table lists inventory plot level carbon estimates for the above ground carbon pool.

- The Above Ground Carbon Table fields are described in Table 8 below. T0, t1 and t2 in the table refer to the growth cycles 0, 1 and 2 representing 2005, 2006 and 2007 (for Carbwini2005. If the Carbwxxx file is for 2009, then t0 will be 2009.

Field Name	Description	Units
PlotID	Plot ID	None
Area_ha	Area of Plot (default =0.05)	ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest catgory lookup ID (user defined)	None
AB_deadtree_C_t01	Dead above ground biomass (AB) time (t1)	tC/plot
AB_Living_C_t01	Living AB biomass t1	tC/plot
Mortality_AB_t01	AB mortality t1	tC/plot
Thin_AB_t01	AB thinnings t 1	tC/plot
CF_AB_t01	AB clearfells t1	tC/plot
AB_C_t01	AB form t1	tC/plot
Litterfall_C_t01	Litterfall t1	tC/plot
SB_from_thin_C_t01	Stem biomass (SB) from thinning t1	tC/plot
SB_from_cf_C_t01	Stem biomass (SB) from clearfell t1	tC/plot
HWP_t01	Timber biomass to harvested wood product (HWP) pools t1. Note Harvested timber is assumed to be immediate oxidised following harvest but timber is allocated to the HWP table is further analysis is required	tC/plot
HR_t01	Timber harvest residue let of site (default assumed a constant value of 4 % of timber harvested)	tC/plot
AB_C_gain_t01	AB_C_t01 minus AB living plus mortality, Thin and cleafell t01(negative value represents a gain)	tC/plot
AB_C_loss_tn01	sum of AB mortality, litter, SB from CF and Thin t01	tC/plot
Net_AB_t01	sum AB_C_gain and AB_C_loss	tC/plot
AB_deadtree_C_t02	dead tree AB (from mortality model)	tC/plot
AB_Living_C_t02	Living AB biomass t2	tC/plot
Mortality_AB_t02	AB mortality t2	tC/plot
Thin_AB_t02	AB thinnings t 2	tC/plot
CF_AB_t02	AB clearfells t2	tC/plot
AB_C_t02	AB form t2	tC/plot
Litterfall_C_t02	Litterfall t2	tC/plot
SB_from_thin_C_t02	Stem biomass (SB) from thinning t2	tC/plot
SB_from_cf_C_t02	Stem biomass (SB) from clearfell t2	tC/plot
HWP_t02	HWP t2	tC/plot
HR_t02	HR t2	tC/plot
AB_C_gain_t02	AB_C_t02 minus AB_C_t01 plus mortality thinning and clearfell t02(negative value represents a gain)	tC/plot
AB_C_loss_tn02	sum of AB mortality, litter, SB from CF and Thin t02	tC/plot
Net_AB_t02	sum AB_C_gain and AB_C_loss	tC/plot

Table 8 – Description of Above Ground Carbon Table Fields in the IncrementsDB.mdb database

9.2.2 Below Ground Carbon Table

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_BG**. In this example, the project name is **Project_1** and so the project specific Below Ground Carbon Table is named **Project_1_BG**. This table lists inventory plot level carbon estimates for the below ground carbon pool.

Field Name	Description	Units
PlotID	Plot ID	None
Area_ha	Area of Plot (default =0.05)	ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest category lookup ID (user defined)	None
RB_deadtree_C_t01	Dead root biomass (RB) time (t1)	tC/plot
RB_Living_C_t01	Living RB biomass t1	tC/plot
Mortality_RB_t01	RB mortality t1	tC/plot
Thin_RB_t01	RB thinnings t 1	tC/plot
CF_RB_t01	RB clearfells t1	tC/plot
RB_C_t01	RB form t1	tC/plot
RB_C_gain_t01	RB_C_t01 minus RBliving plus mortality, Thin and CF t01 (negative value represents a gain)	tC/plot
RB_C_loss_tn01	sum of RB mortality, RB from CF and Thin	tC/plot
Net_RB_t01	sum RB_C_gain and RB_C_loss	tC/plot
RB_deadtree_C_t02	dead tree RB (from mortality model)	tC/plot
RB_Living_C_t02	Living RB biomass t2	tC/plot
Mortality_RB_t02	RB mortality t2	tC/plot
Thin_RB_t02	RB thinnings t 2	tC/plot
CF_RB_t02	RB clearfells t2	tC/plot
RB_C_t02	RB form t2	tC/plot
RB_C_gain_t02	RB_C_t02 minus RB_C_t01 plus mortality, Thin and CF t02 (negative value represents a gain)	tC/plot
RB_C_loss_tn02	sum of RB mortality,RB fromCF and Thin t2	tC/plot
Net_AB_t02	sum RB_C_gain and RB_C_loss	tC/plot

Table 9 – Description of Below Ground Carbon Table Fields in the IncrementsDB.mdb database

9.2.3 Deadwood Carbon Table

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_DeadWood**. In this example, the project name is **Project_1** and so the project specific DeadWood Carbon Table is named **Project_1_Deadwood**. This table lists inventory plot level carbon estimates for the deadwood carbon pool (all wood with diameter greater than 7cm and includes roots with diameter less than 5cm).

Field Name	Description	Units
PlotID	Plot ID	None
Area_ha	Area of Plot (default =0.05)	ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest category lookup ID (user defined)	None
Stump_C_t0	Stump biomass t0 (from inventory or other model)	tC/plot
Deadlog_C_t0	Deadlog biomass t0 (from inventory or other model)	tC/plot
Standing_deadwood_t0	From AB standing deadwood	tC/plot
Deadwood_t01	Stump_C_t0, Standing t0 and Deadlog_C_t0	tC/plot
HR_logs_t01	harvest residue from AB TH and CF	tC/plot
HR_root_t01	harvest residue from RB TH, CF and mortality	tC/plot
Standing _deadwood_t01	deadwood from mortality model t1	tC/plot
Deadwood_in_t01	Stump_C_t1, standing t1 and Deadlog_C_t1	tC/plot
Deadwood_out_t01	decomposition of cumulative deadwood t0 and t1	tC/plot
Net_deadwood_t01	Deadwood_in_t01 minus deadwood out_t01	tC/plot
Deadwood_t02	(deadwood t1 + t0)-decomposition	tC/plot
HR_logs_t02	harvest residue from AB TH and CF	tC/plot
HR_root_t02	harvest residue from RB TH, CF and mortality	tC/plot
Standing _deadwood_t02	deadwood from mortality model t2	tC/plot
Deadwood_in_t02	Stump_C_t2, standing t2 and Deadlog_C_t2	tC/plot
Deadwood_out_t02	decomposition of cumulative deadwood t2	tC/plot
Net_deadwood_t02	Deadwood_in_t02 minus deadwood out_t02	tC/plot

Table 10 – Description of Deadwood Carbon Table Fields in the IncrementsDB.mdb database

9.2.4 Litter Carbon Table

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_Litter**. In this example, the project name is **Project_1** and so the project specific Litter Carbon Table is named **Project_1_Litter**. This table lists inventory plot level carbon estimates for the litter carbon pool (all wood with diameter less than 7cm).

Field Name	Description	Units
PlotID	Plot ID	None
Area_ha	Area of Plot (default =0.05)	ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest category lookup ID (user defined)	None
net_litter_t0	Litter biomass t0 (from inventory or lookup model)	tC/plot
Litter_input_t01	From AG table litterfall t1	tC/plot
Mortality_LT_t01	Litter and branch from mortality t1	tC/plot
Thin_AB_t01	Litter (top, leaf and branch) from thinning t1	tC/plot
CF_AB_t01	Litter (top, leaf and branch) from clearfell t2	tC/plot
T_Litter_in_t01	Mort LT, Thin_AB, CF_AB_Litter input t1	tC/plot
T_Litter_out_t01	Decomposition of accumulated T_litter in t01 and net_litter_t0	tC/plot
Net_Litter_t01	T-Litter-in minus T litter out (t1)	tC/plot
Litter_Stock_t01	(net_Litter t0 and T_litter t1) minus decomposition	tC/plot
Litter_input_t02	(deadwood t1 + t0)-Deadwood_t01	tC/plot
Mortality_LT_t02	Litter and branch from mortality t1	tC/plot
Thin_AB_t02	Litter (top, leaf and branch) from thinning t1	tC/plot
CF_AB_t02	Litter (top, leaf and branch) from clearfell t2	tC/plot
T_Litter_in_t02	Mort LT, Thin_AB, CF_AB_Litter input t2	tC/plot
T_Litter_out_t02	Decomposition of accumulated T_litter in t01, t02 and net_litter_t0	tC/plot
Net_Litter_t02	T-Litter-in minus T litter out (t1)	tC/plot
Litter_Stock_t02	(net_Litter t0 and T_litter t1, t2) minus decomposition	tC/plot

Table 11 – Description of Litter Carbon Table Fields in the IncrementsDB.mdb database

9.2.5 Soil Carbon Table

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_Soil**. In this example, the project name is **Project_1** and so the project specific Soil Carbon Table is named **Project_1_Soil**.

Field Name	Decription	Unit
PlotID	Plot ID	None
Area_ha	Area of Plot (default =0.05)	Ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest category lookup ID (user defined)	None
CARBWARE_soil	Soil code from Lookup (see soil lookup and soiltype_lookup xls)	None
Soil_EF_Category	1 = peats, 2 =peaty=mineral and 3= mineral soils	None
Drainage	poor (100) to good (500)	None
SoilDepth_cm	soil depth in cm	cm
PeatDepth_cm	peat depth in cm	cm
EPA_SoilGroups	NFI and Epa description (not used)	None
EF_soil	emission factor for peats (defualt 0.59)	t C ha-1 yr-1
ADJ_EF_SOIL	EF_soil * (PeatDepth/30) if peat depth is less than 30 cm for peaty-mineral soils	t C ha-1 yr-1
Net_soil_	emission per plot per year	t C plot-1 yr-1

Table 12 – Description of Soil Carbon Table Fields in the IncrementsDB.mdb database

9.2.6 Harvested Wood Products Carbon Table

- This project specific CARBWARE Table is created and named by CARBWARE using the naming convention **Project Name_HWP**. In this example, the project name is **Project_1** and so the project specific HWP Carbon Table is named **Project_1_HWP**. Note this just stores the HWP C form harvests specified in the Events table. HWP C storage is not included in the current version of CARBWARE

Field Name	Decription	Unit
PlotID	Plot ID	None
Area_ha	Area of Plot (defualt =0.05)	ha
County	County lookup ID (user defined)	None
Ownership	Ownership lookup ID (user defined)	None
LandUseField	Land use lookup ID (user defined)	None
Soil_EF_Field	Soil EF ID lookup ID (user defined)	None
Forest_Category_ID	Forest category lookup ID (user defined)	None
Harv_Thin01	Harvested C from thinnings t1	tC/plot
Harv_clearfell01	Harvested C from clearfell t1	tC/plot
Tot_Harvest_tC01	Total harvest C for t1	tC/plot
Thin_Harvest_m301	Harvested volume from thinnings t1	m3/plot
CF_Harvest_m301	Harvested volume from clearfell t1	m3/plot
Harvest_m301	Total harvest volume for t1	m3/plot
Harv_Thin02	Harvested C from thinnings t2	tC/plot
Harv_clearfell02	Harvested C from clearfell t2	tC/plot
Tot_Harvest_tC02	Total harvest C for t2	tC/plot
Thin_Harvest_m302	Harvested volume from thinnings t2	m3/plot
CF_Harvest_m302	Harvested volume from clearfell t2	m3/plot
Harvest_m302	Total harvest volume for t2	m3/plot

Table 13 – Description of HWP Carbon Table Fields in the IncrementsDB.mdb database

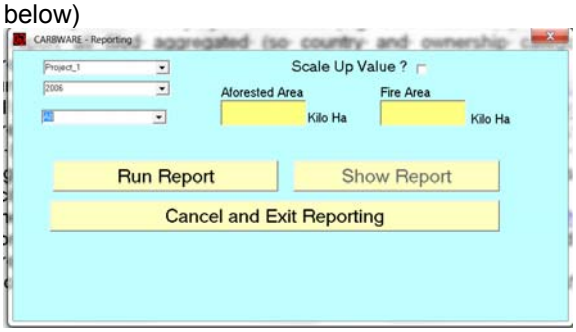
10 The Reporting Module

The reporting module aggregates the plot level information for each carbon pool (see allocation tables in section 9.2) to a national or regional level. The reporting format is designed to be interoperable with the UNFCCC common reporting tables:
http://unfccc.int/national_reports/annex_i_ghg_inventories/reporting_requirements/items/2759.php

10.1 Selecting the Project, reporting year and level of aggregation

- Open the reporting module.
- Select project (e.g. **Project_1**) from drop down list
- Select the reporting year from drop down list (see screen shot below)- the first year from the growth simulation is 2006 in this case.
- Select the reporting category from drop down list. Reporting results table can be aggregated at 3 levels depending on information required. The aggregation fields (county and ownership) are defined in the **Lookup** table in the project data base (e.g. Carbwini2005).
    - **All**, report all fields aggregated (so country and ownership categories are not sub-categorised).
    - **County**: The default values for county are shown in the county_lookup.xls file on the instillation disc. The user can modify this lookup value according to level of aggregation required. This does not necessarily have to be counties, although the field header will not change if other categories are defined. Selection of the county category will provide aggregated values for forest categories and soil types (as specified in the Lookup table) for each county.
    - **Ownership:** The default values for ownership are shown in the ownership_lookup.xls file on the instillation disc. The user can modify this lookup value according to level of aggregation required.

In this example ALL forest and soil categores are agrregated into repective carbon pools (see screen shot below)



10.2 Scale Up Value Option and Afforested & Fire Area Inputs

This function is included to adjust for scaling up of plot information to the final forest area or reported reported. Using Carbwini2005 and Project_1 as an example, the number of plots (representing 400 ha per plot i.e. plots at a 2 x 2 km sampling grid) is 146, which represents 58400 ha. If the inventory has more detailed estimates of area (e.g. remote sensing data of detailed vector data sets) then a scale up adjustement can be made.

- If there are additional areas not included in ther inventory, such as fires, these can be subtracted from the afforested area. In this example 100 ha (0.1 kha) were detected using other data sources. Note that there are no calculations for carbon stocks, these have to be done using user

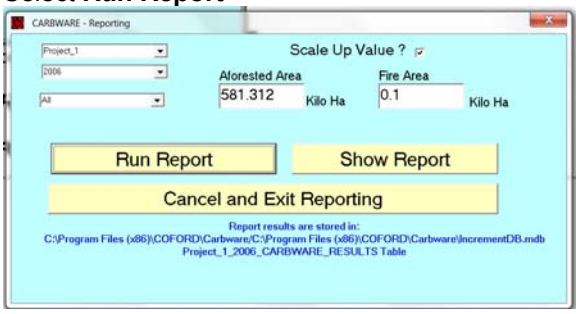
defined methods and added to the final reported after the anlaysis is complete (refer to Duffy et al. 2011 and the IPCC GPG, 2006, for sytems used for Irish reporting of fires)

- If more accurante data sources suggest that the scaled up area is 58412 ha, for example, enter the new areas in Kha under the Aforested area (581.412 kha) then the scaled up forest area should be 581.312 kha with 0.1 kha entered under fires as shown below.
- Tick the scale up box and enter relevent vlaues in clear boxes (see screen shot below)
- If the scale up area is the same and no additonal area are added do not select the Scale up Value tick box

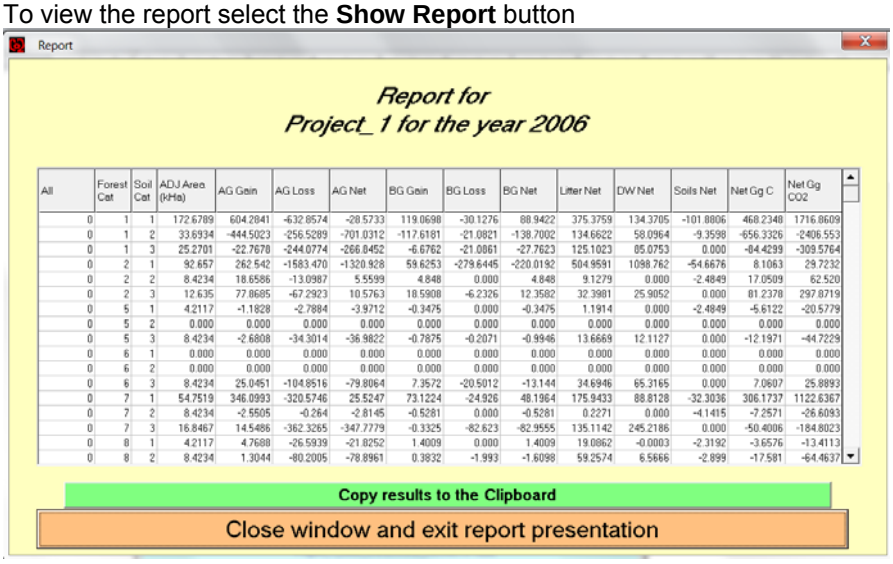
The report can now be generated

10.3 Running a Report & Viewing a Report Table

- Select **Run Report**

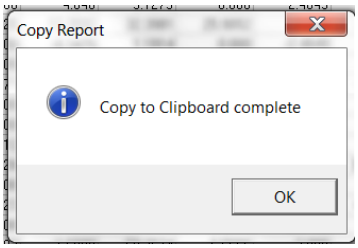


- The location of the report table in the IncrementDB is shown in blue text at the bottom of the screen
- To view the report select the **Show Report** button



All	Forest Cat	Soil Cat	ADJ Area (kHa)	AG Gain	AG Loss	AG Net	BG Gain	BG Loss	BG Net	Litter Net	DW Net	Soils Net	Net Gg C	Net Gg CO2
0	1	1	172.6789	604.2841	-632.8574	-28.5733	119.0698	-30.1276	88.9422	375.3759	134.3705	-101.8806	468.2348	1716.8609
0	1	2	33.6934	-444.5023	-256.5289	-701.0312	-117.6181	-21.0821	-138.7002	134.6622	58.0964	-9.3598	-656.3326	-2406.553
0	1	3	25.2701	-22.7678	-244.0774	-266.8452	-6.6762	-21.0861	-27.7623	125.1023	85.0753	0.000	-84.4299	-309.5764
0	2	1	92.657	262.542	-1583.470	-1320.928	59.6253	-279.6445	-220.0192	504.9591	1098.762	-54.6676	8.1063	29.7232
0	2	2	8.4234	18.6586	-13.0987	5.5599	4.848	0.000	4.848	9.1279	0.000	-2.4849	17.0509	62.520
0	2	3	12.635	77.8685	-67.2923	10.5763	18.5908	-6.2326	12.3582	32.3981	25.9052	0.000	81.2378	297.8719
0	5	1	4.2117	-1.1828	-2.7884	-3.9712	-0.3475	0.000	-0.3475	1.1914	0.000	-2.4849	-5.6122	-20.5779
0	5	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	5	3	8.4234	-2.6808	-34.3014	-36.9822	-0.7875	-0.2071	-0.9946	13.6669	12.1127	0.000	-12.1971	-44.7229
0	6	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	6	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	6	3	8.4234	25.0451	-104.8516	-79.8064	7.3572	-20.5012	-13.144	34.6946	65.3165	0.000	7.0607	25.8893
0	7	1	54.7519	346.0993	-320.5746	25.5247	73.1224	-24.926	48.1964	175.9433	88.8128	-32.3036	306.1737	1122.6367
0	7	2	8.4234	-2.5505	-0.264	-2.8145	-0.5281	0.000	-0.5281	0.2271	0.000	-4.1415	-7.2571	-26.6093
0	7	3	16.8467	14.5486	-362.3265	-347.7779	-0.3325	-82.623	-82.9555	135.1142	245.2186	0.000	-50.4006	-184.8023
0	8	1	4.2117	4.7688	-26.5939	-21.8252	1.4009	0.000	1.4009	19.0862	-0.0003	-2.3192	-3.6576	-13.4113
0	8	2	8.4234	1.3044	-80.2005	-78.8961	0.3832	-1.993	-1.6098	59.2574	6.5666	-2.899	-17.581	-64.4637

- The results table can be exported to Excel by selecting the green **Copy results to Clipboard** button.
- A pop up window confirming the export is shown, click OK



- Open excel and a new worksheet and paste the copies cells. Save in you project record with a relevant file name**.**
- Explanation of field headers and results are shown in Table x below

Field Name	Description	Unit
Category	All categories are aggregated	none
Forest Cat	Forest category as specified in Lookup table (see Table1 section 4)	none
Soil Cat	Soil category as specified in Lookup table under Soil_EF category (see Table1 section 4). Note that these can be user defined in the Lookup table	none
ADJ Area	Area within in each category, this may be adjusted if Scale Up Value was selected	kHa
AG gain	Above ground biomass gain	Gg C Note positive is an uptake negative a loss of C
AG net	Net above ground biomass loss or gain	Gg C
BG gain	Below ground biomass gain	Gg C
BG loss	Below ground biomass loss	Gg C
BG net	Net below round loss or gain	Gg C
Litter Net	Litter net gain or loss (note includes all litter and wood with diameter less than 7 cm)	Gg C
DW Net	Deadwood net gain or loss (note includes all wood with diameter greater than 7 cm)	Gg C
Soil Net	Soil net gain or loss (note default values mineral soils are assumed to be zero, but an EF is applied all organic soils)	Gg C
Net Gg C	Net gain or loss of C from all pools	Gg C
Net Gg CO_2	Net gain or loss of CO_2	Gg CO_2

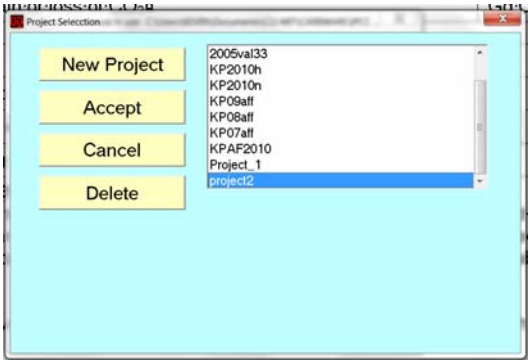
11 Managing Carbware Databases

The IncrementDB stores all intermediate and reported data files. These can accumulate and take up a lot of disc space. The data can be deleted and databases should be compacted and repaired to avoid accumulation of unwanted data or creation of large memory space requirements for the database.

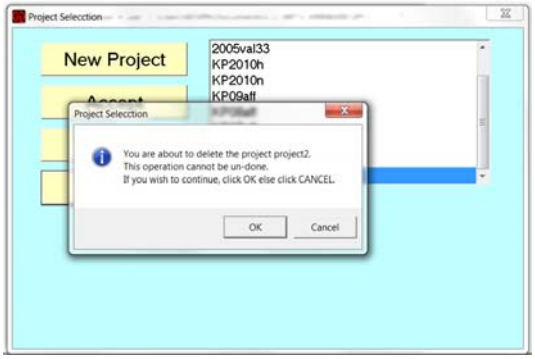
11.1 Deleting projects

If you have created an unwanted project, all data from these can be deleted from the Assess database.

- Open Carbware
- Select Choose project
- Select the project you wish to delete (e.g. Project2 below)



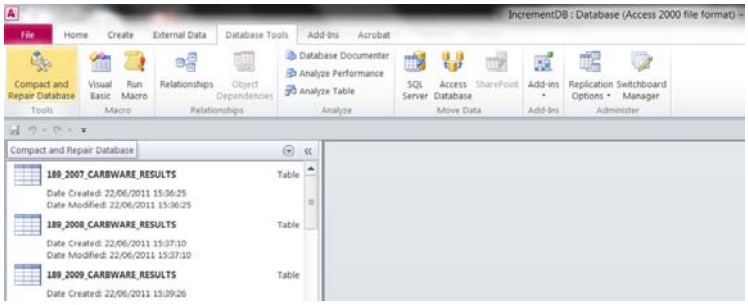
- Select Delete
- A pop up warning will confirm that this Project will be deleted and promts the use to select OK, or Cancel if this is the wrong selection
- Click OK and all files output files in the IncremetnDB related to the project will be deleted
- Note the input database will not be effected (e.g.Carbwini2005)



11.2 Compacting and reparing databases

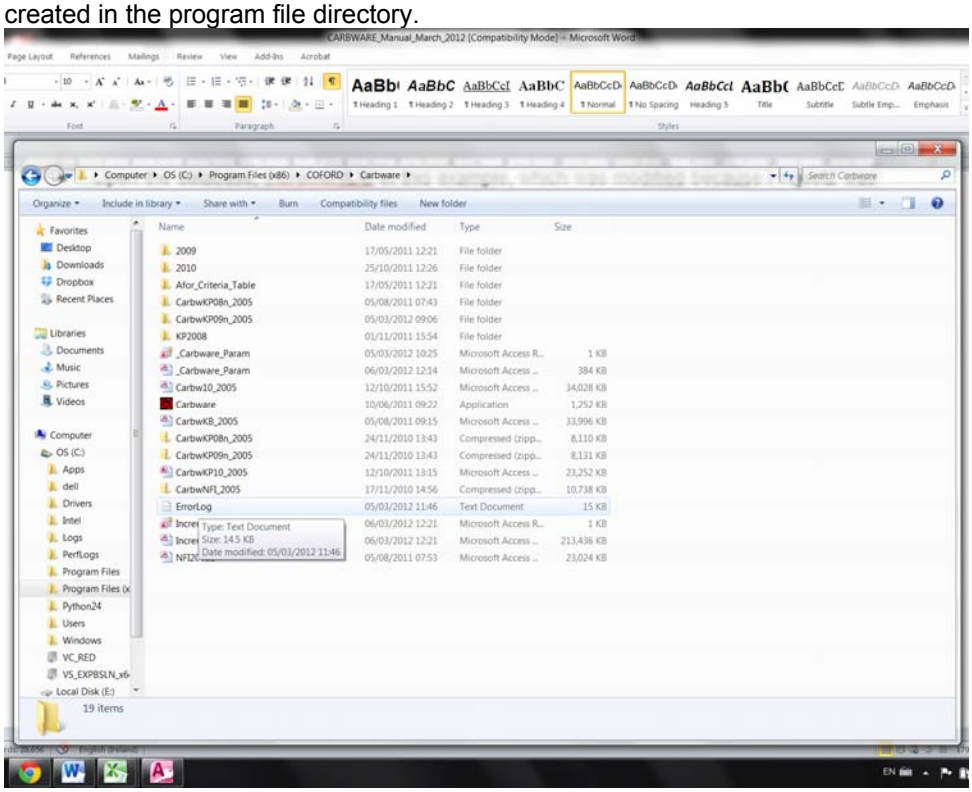
If databases in Access are modified, it is good proactrive to compact and repair the database to avoud redundant disc space usage and minimise database interoperability issues. This can be done in Access:

- Open the database, IncrementDB in this example, which was modified because Project2 was deleted
- Select the Database Tools menu and then the Compact and repair ribbon in Access2010 or Compact and repair drop down for Access 2007 and earlier
- The Database with be repaired and compacted, you will see the disc allocation space has reduced

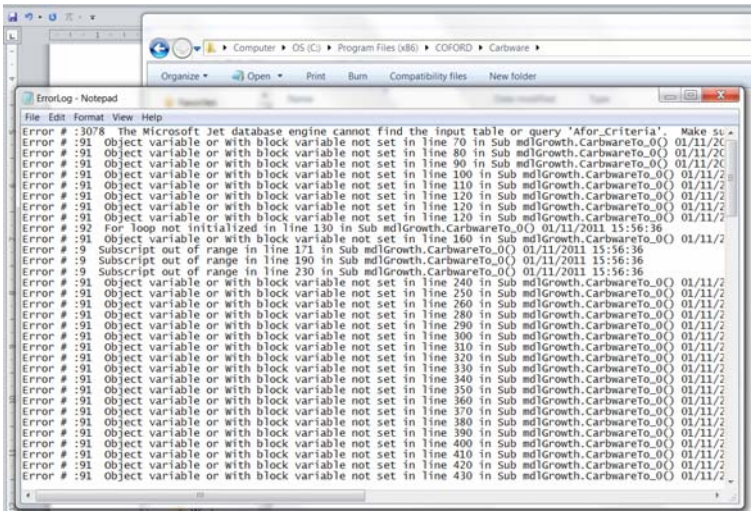


11.3 Error log

If there is run time error or variable violation during the running of CARBWARE a error log file will be created in the program file directory.



- Open the file to display the error log



In this case the input table ‘Afor_Criteria’ was not included in the Carbwxxx file or there was an Field name error as specified by the ‘object variable or with block variablr not set..’ error

Errors can occur for many reasons, but the most common reasons include

- Exclusion of required input field or tables
- Incorrect entry of field header names
- Entry of incorrect numeric values e.g. DBH = 1234 cm

Appendix 1

Appendix 1A: Allometric biomass equations (used in allocation module)

Table 1: Allometric equations used to calculate biomass component for individual trees (kg d.wt tree^{-1}). Similar species are grouped into 6 different cohorts based on available research information (Spruces, Pines, Larches, Other conifers, fast growing broadleaves and slow growing broadleaves). Abbreviations: AB-above ground, TB-total biomass, BB-below ground, FB-foliage, SB-stem (i.e timber >7cm diameter), L_{HR}= lop and top from harvest residues, DBH diameter at breast height (1.3 m) in cm, H –height in m.

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
Spruce											
1	AB	H>4.5m	$a \times DBH^{b} + c \times H^{d}$	0.23	2.12	5 x 10^{-7}	4.99	0.91	0.29	1.01	i, ii
2	AB	H<4.5m	$a \times H^{b} \times c$	1.32	1.7	1.38		0.86	0.2	1.1	i, ii
3	TB		$\exp\left[Ln(a) + b \times Ln(AG)\right]$	1.02	1.033			0.91	0.08	1.03	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp\left[-c \times AB\right]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
6	SB		$\exp\left[Ln(a) + b \times Ln(AG)\right]$	0.405	1.09			0.99	2.99	1.03	ii, iii
7	L_{HR}		AB-SB								
Pines											
8	AB	H>3.8m	$a \times DBH^{b} + c \times H^{d}$	0.07	2.42	0.039	2.51	0.93	0.13	0.94	ii, iii
9	AB	H<3.8m	$a \times H^{b}$	0.12	3.91			0.95	0.74	0.95	i, ii
10	TB		$\exp\left[Ln(a) + b \times Ln(AG)\right]$	1.15	1.01			0.96	0.4	1.01	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp\left[-c \times AB\right]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
11	SB		$\exp\left[Ln(a) + b \times Ln(AG)\right]$	0.71	1.005			0.97	0.27	0.96	ii, iii
7	L_{HR}		AB-SB								
Larch											
12	AB	H>2m	$a \times DBH^{b} + c \times H^{d}$	0.11	2.31	0.001	3.29	0.94	0.27	0.94	ii, iii
13	AB	H<2m	$a \times H^{b}$	0.03	1.91			0.67	0.44	1.2	i, ii
14	TB		$\exp\left[Ln(a) + b \times Ln(AG)\right]$	1.43	0.98			0.99	0.25	0.99	ii, iii
4	BB		TB-AB								

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
15	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.903	0.972			0.98	0.28	0.96	ii, iii
7	L_{HR}		AB-SB								
Other conifers											
16	AB	H>3.8m	$a \times DBH^{b} + c \times H^{d}$	0.022	2.73	0.19	2.06	0.96	0.46	1.008	ii, iii
17	AB	H<3.8m	$a \times H^{b} \times c$	0.005	1.58	1.12		0.86	0.28	1.02	i, ii
18	TB		$\exp[Ln(a) + b \times Ln(AG)]$	1.59	0.96			0.99	0.28	1.005	ii, iii
4	BB		TB-AB								
5	FB		$AB \times a + b \times \exp[-c \times AB]$	0.025	0.089	0.003		0.68	3.4	0.98	i, ii
19	SB		$\exp[Ln(a) + b \times Ln(AG)]$	0.89	0.96			0.98	0.57	1.055	ii, iii
7	L_{HR}		AB-SB								
Slow growing broadleaves											
20	AB	H>3.0m	$a + \left[\frac{b \times DBH^{c}}{DBH^{c} + 246872}\right]$	0.08	25000	2.5	246872				iv
21	AB	H<3.0m	$a \times H^{b}$	0.031	1.72			0.84	0.88	0.91	i, ii
22	BB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
23	FB	DBH>10cm	$a \times (DBH \times 10)^{b}$	0.009	1.47			0.96			v
24	FB	DBH<10cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
25	SB	DBH>19cm	$a \times (DBH \times 10)^{b}$	0.0002	2.5			0.97			v
26	SB	DBH<9cm	$\frac{AB + BB}{1.4}$								BEF
7	L_{HR}		AB-SB								
Slow growing broadleaves											
20	AB	H>3.0m	$a + \left[\frac{b \times DBH^{c}}{DBH^{c} + 246872}\right]$	0.06	25000	2.5	246872				iv

Eq	Function	Range	Equation	Coefficients				r^2	RMSE	Slope	Source
				a	b	c	d				
21	AB	H<3.0m	$a \times H^b$	0.031	1.72			0.84	0.88	0.91	i, ii
22	BB		$\exp(-a + Ln(DBH) + b)$	1.509	0.284						iv
27	FB	DBH>3cm	$a + b \times DBH^c$	0.375	0.0024	2.517		0.90			vi
28	FB	DBH<3cm	$AB \times 0.3$					0.78	1.2	0.79	i, ii
29	SB	DBH>35cm	$a \times DBH^b$	0.0001	2.535			0.97			v
30	SB	DBH<9cm	$\frac{AB + BB}{1.4}$								BEF, vii
7	L_{HR}		AB-SB								

i. National research harvested tree database (COFORD funded project CARBiFOR)
ii Black et al., Biomass equations for modelling C dynamics in Irish forests (in prep)
iii Forest Research pulled tree database (Brice Nicholl, NRS, Forest Research, UK)
iv Brown S (2002) . Measuring carbon in forests: current status and future challenges. Environmental Pollution 116: 363-372.
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vii. Black K., Tobin B., Saiz G., Byrne K. & Osborne B. (2004). Improved estimates of biomass expansion factors for Sitka spruce. Irish Forestry 61: 50 –65.

Appendix 1B: CARBWARE growth models and pre-processing functions

The NFI permanent plot sampling procedure does not sample all trees in a plot (see Figure 11.4). Therefore, it is not possible to derive productivity index information, such as Height index or Yield class, which can be used to drive conventional stand based productivity models. The alternative and most statistically valid procedure adopted was the use of single tree models, to simulate tree growth between NFI cycles. These models can be cross-validated and re-parameterised once a repeat NFI cycle is completed. This section discussed the development of the CARBWARE growth model from draft versions for submission to International, peer reviewed Scientific Journals.

Pre-processing functions

Height-Diameter And Crown Ratio Modelling For Six Species Cohorts.

It is common among forestry datasets that tree height (H) or crown ratio (CR) is not measured on every tree. This creates interest in estimating the height of such trees.

A common forest inventory approach used to derive missing H and CR values involves the use of single parameter (DBH) models based on species and plot specific predictions (NFI, 2007; Wykoff et al., 1982). However, is has been suggested that these Chapman-Richards functions, or derivations there of, are problematic because the function approaches the asymptote too rapidly, particularly when there is a weak relationship between DBH and H in larger trees. In addition, individual plot DBH-H data is sometimes too sparse to parameterise plot specific functions. Generalised DBH-H functions avoid the need to parameterise relationship for every stand. Since the relationship between DBH and H is influenced by the relative competitive position of trees within a stand and management interventions, site-level stand-density information is often incorporated (Temesgen and Gadow, 2004). Taking their results as a starting point, we address here several issues that arise in the context of our modelling dataset. These include the application of nonlinear mixed effects models which successfully borrow strength across all permanent plots, thereby facilitating imputation in plots where data is sparse or unevenly distributed. The permanent sample plot data, taken from a range of spacing and thinning experiments, used in this study is well suited, albeit not arising by design, to evaluate these stand-density parameters to describe variations in H and CR across different silvicultural conditions.

Materials and methods

Data

Data used were obtained from Coillte Teoranta's (the Irish Forestry Board state commercial forestry company) permanent sample plot record system. The dataset contains records from many silvicultural and thinning trials established during the period 1963 to 2001. The trials were initially established as replicated experimental designs with repeated measurements typically undertaken every five years. The dataset is described in Broad and Lynch (2007).

Incorporating competition covariates

The modelling here follows Temesgen and Gadow (2004) who based their work on Yang et al. (1978) and incorporated competition covariates into the Yang/Weibull function (Table 1, Model 2).
We evaluate that model and also use test for differences between management regimes conditional on the DBH-H model by incorporating dummy indicator variables in the linear regression models of the model parameters.
Our aim in this section was to test if the inclusion of certain covariates, typically relating to the competition in a forest stand/plot, improved the baseline DBH-H model (Table 1, Model 1). We also investigated whether the model was improved by including random effects on the level of the plot (Table 1, Model 3).
The competition covariates are plot basal area (BA, m^2 ha^{-1}), basal area in larger trees (BAL, m^2 ha^{-1}) which is the integral of the empirical frequency distribution of the BA variable from the subject tree to the

largest diameter tree in the plot and plot density (DENS, trees ha^{-1}). Models were fitted in NLMixed procedure in SAS using the Trust-Region algorithm. Grids were specified as starting values for parameters where sensible.

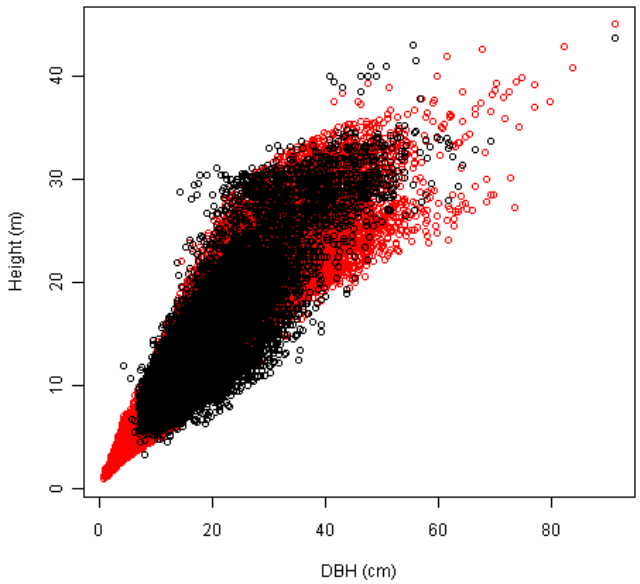

Figure 1: Model 2 Height estimates (red) and actual heights (black). The estimates presented here depict a “cloud” because they are conditioned on covariates that vary between trees (BAL) and plots (Density, Basal Area) and over time (BAL, Density, BA).

Number	Model	-2l	BIC
1	$H = a(1-\exp(b.DBH^{c}))$	65185	65223
2	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(b.DBH^{(c_1 - c_2 BAL)}))$	58341	58417
3	$H = (Ui + a_1 + a_2 BAL + a_3 DENS + a_4 BA)(1-\exp(b.DBH^{(c_1 - c_2 BAL)}))$	44980	45034

Table 1. Likelihood statistics for different forms of the DBH-H model.
Model 2 is the model used in CARBWARE for the 6 different cohorts. If dependent variables had no significant influence on the H model prediction, these variables were excluded from the model.

Cohort	Model (2 variation)	a1	a2	a3	b	c1	c2
Spruce	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(b.DBH^{(c_1 - c_2 BAL)}))$	33.69	-0.274	0.1603	0.024	0.8846	0.0064
Pine	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(-b.BAL))$	16.905	0.083	0.0803	0.042		
Larch	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(-b.BAL))$	32.59	0.1052	0.1229	0.023		
Conifers	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(-b.DBH^{c_1}))$	23.226	0.1381	0.0703	0.027	1.1021	
FGB	$H = (a_1 + a_2 BAL + a_3 BA)(1-\exp(-b.DBH))$	14.661	0.1167	0.0187	0.076		
SGB	$H = (a_1 + a_2 BAL)(1-\exp(-b.DBH^{c}))$	29.677	0.1034		0.044	0.7813	

BAL is the sum of the basal area of all individual trees larger than the subject tree (m^2 per ha)
BA is the basal area of all trees in the plot (normalised to a ha)
DBH is the diameter at breast height (cm)

Table 2. CR models used in CARBWARE for the 6 different cohorts. If dependent variables had no significant influence on the H model prediction, these variables were excluded from the model.
The CR model takes the form of:

$$CR = \frac{\exp(lCR)}{1+\exp(lCR)}$$

where *lCR* is derived from the non linear equations, which may vary for different cohorts.

Cohort	Model (*lCR* variations)	a1	a2	a3	a4	a5	b	c
Spruce	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + a_5\left[\frac{H}{BAL}\right] + bDBH^c$	4.8705	-0.017	-0.397	-0.119	-0.296	0.0003	2
Pine	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + bDBH^c$	3.8478	-0.024	-0.213	-0.137		0.0002	2
Larch	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H$	5.8306	-0.018	-0.794	-0.039			
Conifers	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + bDBH^c$	4.1759	-0.019	-0.394	-0.965		0.0004	2
FGB	$lCR = (a_1 + a_2 BAL + a_3 Ln(CCF) + a_4 H + a_5\left[\frac{H}{DBH}\right] + bDBH^c$	2.4539	-0.009	-0.145	-0.045	-0.591	0.0001	2
SGB	$lCR = (a_1 + a_2 BAL + a_3 H + a_5\left[\frac{H}{BAL}\right]$	1.477	-0.005	-0.017	-0.578			

BAL is the sum of the basal area of all individual trees larger than the subject tree (m^2 per ha)
CCF is the crown competition factor, which is a measure of the crown areas of the subject tree relative to a open grown tree that would not be subjected to crown competition (taken from Hassenhaur, see section B of this appendix)
DBH is the diameter at breast height (cm)
H is height (m) form actual or predicted H estimates (Table 1)

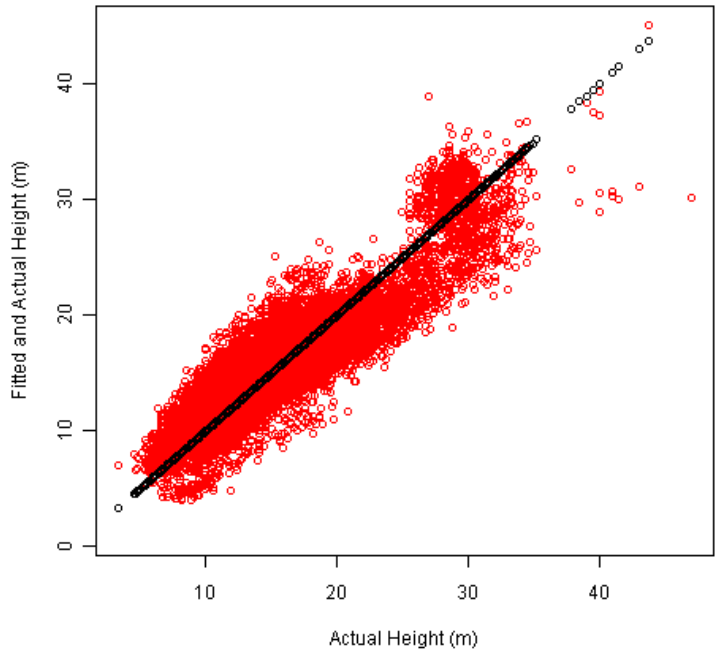

Figure 2 : Fitted and actual height plotted (all cohorts model 2) against actual height.

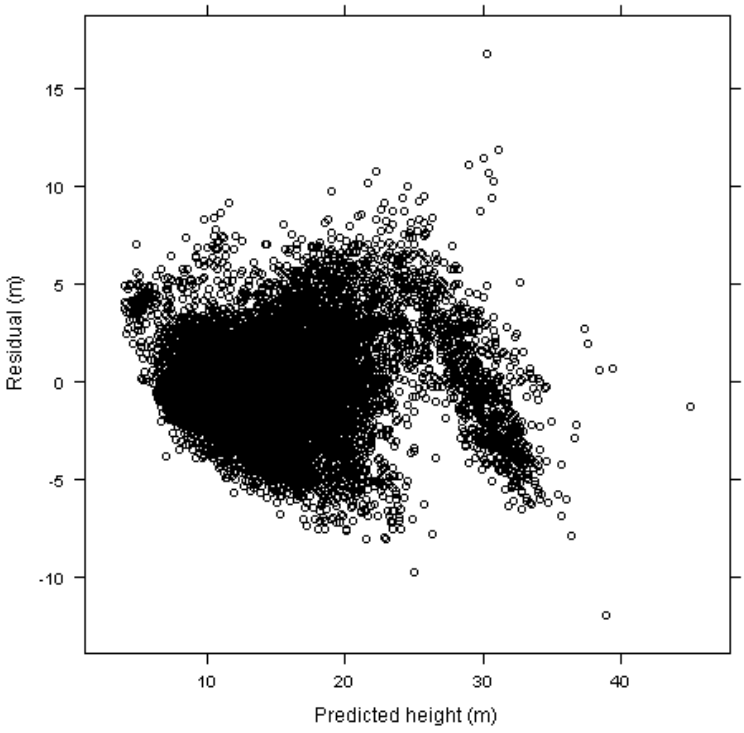

Figure 3 : Raw residuals from the fitted model plotted against the fitted height value.

External validation

Based on the data presented above, model 2 was selected for validation against external data sets. In this section we compare model predictions against data from PSP non-research plots.

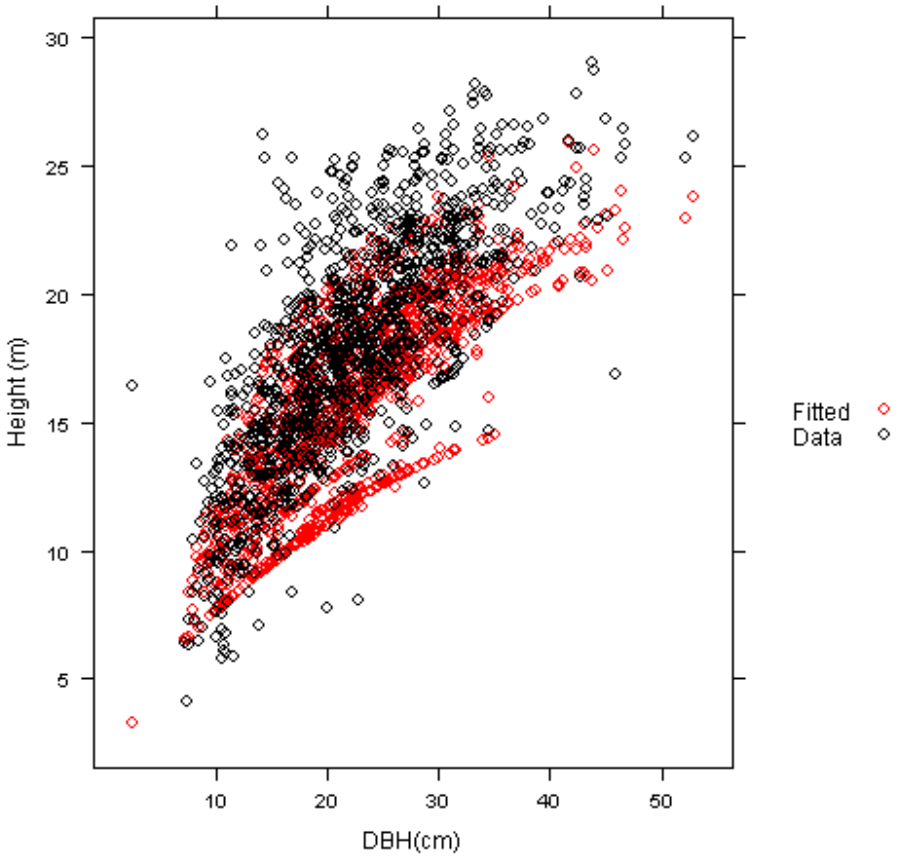

Figure 4 : Estimated and observed validation heights versus DBH.

Generalised and plot-specific models

In this section we discuss the implications of using a generalised DBH-H model (i.e. one whose parameters are fitted to the entire dataset) with a plot-specific model (i.e. one whose parameters are estimated for each plot separately). We compare a mixed effects model and a plot-specific model. The former is plot-specific by the inclusion of a random residual plot effect. In what follows, by *mixed model* we mean the random asymptote model (Table 2, Model 3).

To get an idea of the difference between plot-specific and mixed-model results, we extract a plot from the dataset that exhibits a wide range of DBH and H values and then compare the models for that plot. This makes sense because the context of the comparison is how well a given model will perform for a given plot, primarily. In particular we will compare the standard error of prediction for a new tree height for both models. In the case of the mixed model , this standard error of prediction is derived as conditional on the estimated random plot effect.

A plot-specific Yang/Weibull model gives a smaller standard error of prediction than the same model estimated from the entire dataset, because residual variability for any given model will always increase from a subset of the data (plot specific) to the entire dataset (generalised). In other words, the generalised model predictions are less precise than the plot-specific predictions for any given plot, and the model mean estimate tends *towards* the overall mean and *away* from the plot-specific mean.

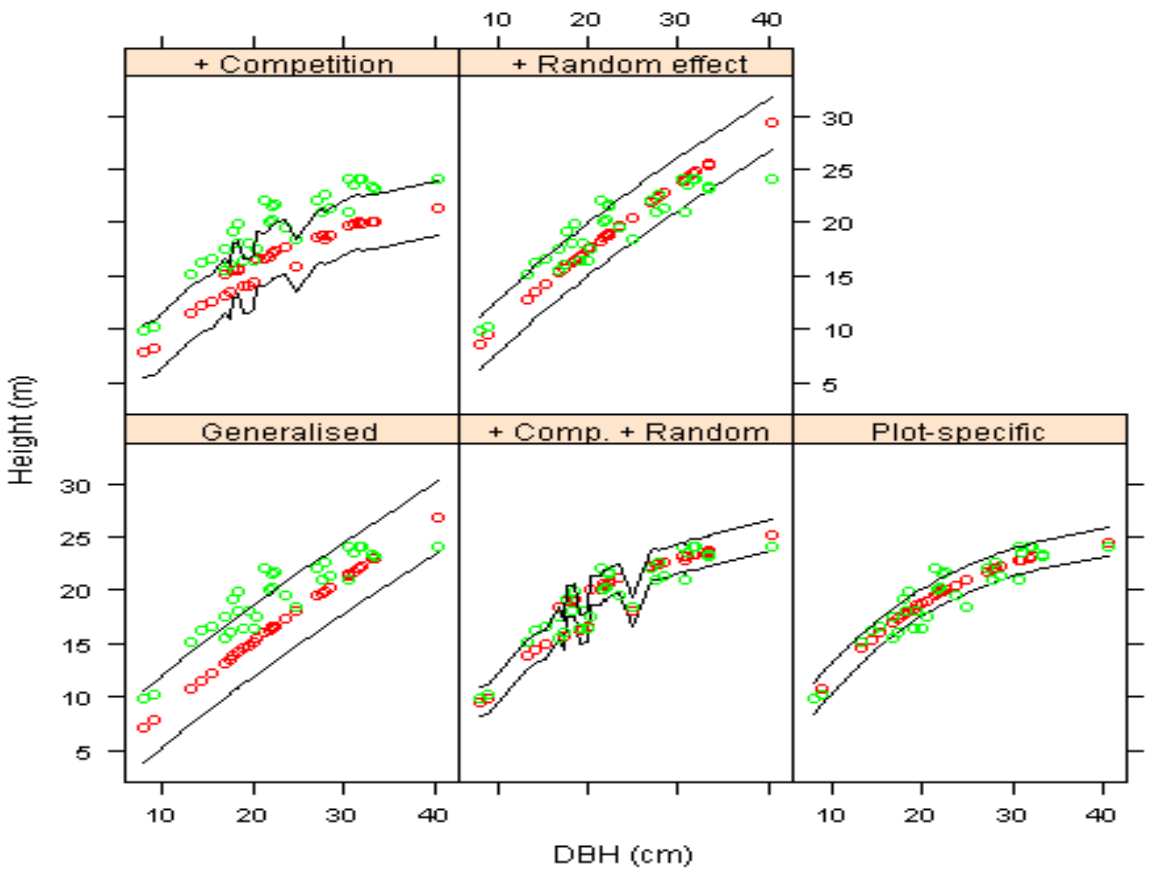

Figure 5 : Model predictions for a single plot with various models, all based on the Yang/Weibull funtion (cf. Table 1). Green, red and black are data, estimates, and single standard error of prediction, respectively. *Competition* denotes a generalised model with competition covariates (cf.Model 2, Table 2), *Random* denotes a plot-specific random asymptote (cf. Model 3, Table 2), *Generalised* denotes parameters are estimated from the entire dataset. The smallest standard error of prediction is associated with the *Plot-specific* model, followed by the + *Comp.* + *Random* model. Average s.e.p. for these models are 1.39 and 1.25 respectively.

Thinning effects

All observations in the dataset were categorised by us as “thinned” or “non-thinned” depending on the general management regime for the plot. We estimated the following model to test for a residual thinning effect, having conditioned on other effects. :

$$H = (U_i + a + a_1 BAL + a_2 DENS + a_3 BA + a_4 I(Thinned))(1 - \exp(b.DBH^{(c_1 - c_2 BAL)}))$$

where I(*Thinned*) is an indicator function valued 1 if the plot was thinned and 0 otherwise. The BIC of this model was 45037, and the Wald test for the a_4 parameter (p = 0.08) indicated that the thinning effect was not statistically significant at the 5% level. The a_4 estimate was greater than zero, perhaps reflecting the longer tail in the height distribution for trees in thinned plots (Figure 7).

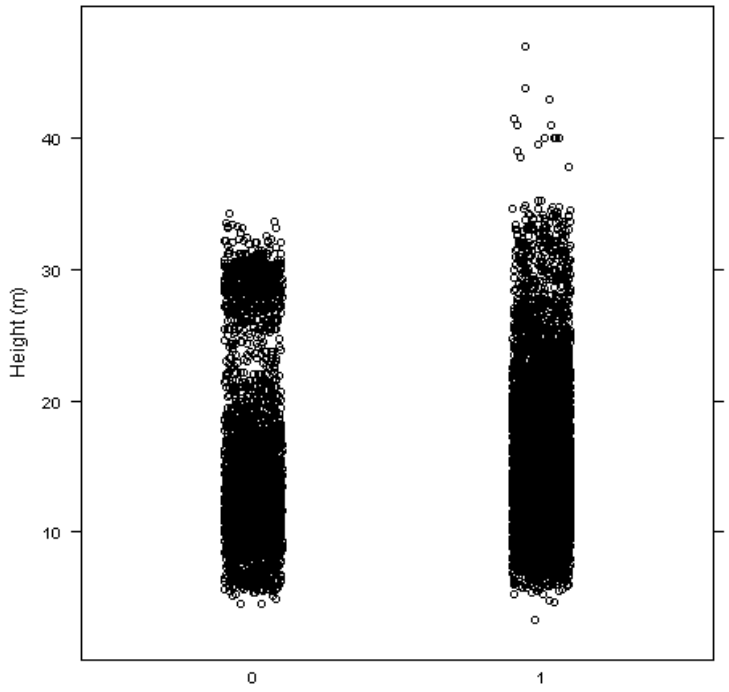

Figure 7. Strip-plot of Heights in the calibration dataset. 1 = Thinned, 0 = Unthinned.

Discussion

We have shown that it is possible to derive a generalised model that performs well and which by its nature deals with the data sparseness issue by estimating the "typical" parameter value and modifying this value as a function of the plot- and tree-level characteristics.
The BIC results and the graphical results suggest that the inclusion of covariates in the model improves the DBH-H model (i.e Model 2), as was shown by Temesgen and von Gadow.

The inclusion of covariates in the model is a move away from the baseline model, which is a generalised approach that presumes that competition (as measured on the scale of the plot by DENS, and BA, and on the scale of the tree by BAL) does not affect the allometric relationship between DBH and H over the tree's lifetime, when subjected to different competition pressure introduced by spacing or thinning. In the next section we address the issue of generalised vs plot specific modelling. However, our results at this point suggest that the Temesgen and von Gadow model that models plot differences through competition variables is a unified single-step approach. By contrast, the plot-specific approach can be seen as a multi-step approach, whereby the DBH-H relationship for each subject is modelled individually, and competition effects are at best implicitly described by the plot-specific fitted parameters. We might suspect that datasets that are heterogeneous across plots might be more accurately modelled using plot-specific approaches. Similarly, a generalised model might perform well on plots that are nearer the centre of the sample space than plots where management conditions are more atypical for a given dataset.
In conclusion, we adopt the use of generalised competition based models in the CARBWARE software because this performs better across all data (See Table 1).

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Appendix 1C: Growth modelling

I) Modelling diameter increments in Irish Forests

Introduction

The modelling approach adapted in this version of CARBWARE v5 is the use of diameter increment models for all trees with a DBH greater that 5cm. This model in a distance independent individual tree growth model parameterised on Coillte permanent plot data recorded every 4 to 6 year since 1954 to 2003. Theses include pure and mixed species stands at establishment planting densities of 5000 to 1000 trees per ha and with different thinning treatments. The advantage of using a single tree growth model and the nature of the parameterisation data set is that different silvicultural regimes and species mixtures can be handled by one generalised modelling framework. In addition, the application data set, i.e. the data from which models will be run, does not contain explicit complete longitudinal data representing stand variable, which are used in conventional growth models.

Data operations

Two datasets are referred to, Coillte permanent sample plot (PSP) and NFI. Some of the data operations referred to below differ between these because the former has complete enumeration on a plot and is longitudinal, the latter samples from the plot and is cross-sectional.

In general, the modelling framework that we base our work on, PrognAus (see various references below), informed the types of data operations required. The framework involves, using their terminology, site, competition and size variables. Our focus was on the latter variables, and site or plot effects were accounted for using mixed model methods, whereby plot or site effects are random, blocking, effects, rather than effects whose levels have physical dimension. In any case, site or plot effects are not a feature of the growth simulator. Furthermore, incomplete enumeration of certain independent variables meant that random effects were difficult to estimate because of the sparse data. We can illustrate that elsewhere but such detail is not relevant to the CARBWARE software manual.

The variables described here are those that feature in the diameter increment model that we aim towards calibrating :

$$Dinc(cm) = \exp(a_0 + a_1 \ln DBH + a_2 DBH^2 + a_3 . \ln CR + a_4 . \ln CCF + a_5 . BAL)$$

See Table 3 and the text for explanation of symbols.

Data operations were concerned with assembling datasets of the variables used in the growth model, insofar as was feasible. Below, we describe any substantive data operations that were performed on the variables of interest. We exclude from this description any operations related to “data cleaning”. The main data cleaning result was to omit negative diameter increments from the dataset. Such omissions were made after such derived variables as BAL, BA and plot density were calculated. That decision was based on the fact that the omission did not have a significant impact on the results, which suggested that no further modelling was necessary to compensate for the omission. Also, if the trees involved were omitted prior to the calculation of derived variables, those variables would have been subject to an even greater bias.

Table 3. Explanation of some symbols used in the text.

Variable	Formula	Scale of measurement
CR	Crown length/height	Range (0,1)
DBH	Diameter at 1.3 m	Cm
Crown competition factor (CCF)	The “open-grown” (e.g. if every tree had zero competitors) crown area of all	Percent

	trees in a plot expressed as a percentage of plot area.	
BAL	A function for each plot that takes as its argument any tree's rank in the diameter distribution ordered from smallest to largest and returns the combined basal area of all trees with higher rank.	M^2 ha^{-1}
BA	Plot basal area.	M^2 ha^{-1}
Annualised diameter increment (Dinc)	(DBH(t+1)-DBH(t))/([t+1] – [t]). DBH(t) stands for "DBH on the occasion of the t^{th} measurement". Since measurment intervals vary, this implies that [t +1] – [t] = 1 is not necessarily true, hence the use of the term "annualised".	cm

.

Open-grown crown width (cw), is an intermediary varible in the calculation CCF. We estimated *cw* using equations derived by Hasenauer (1997). These equations return open-grown crown width in *metres*. Hasenauer (1997) derived species-specific equations that we apply in approximation to cohorts,

Spruce : $cw = \exp(-0.3232)*((DBH)^{0.6441})$
Other conifers : $cw = \exp(0.092)*((DBH)^{0.538})$
Pine : $cw = \exp(-0.1797)*((DBH)^{0.6267})$
Larch : $cw = \exp(-0.3396)*((DBH)^{0.6823})$
Slow-growing broadleaves : $cw = \exp(-0.3973)*((DBH)^{0.7328})$
Fast-growing broadleaves : $cw = \exp(0.1366)*((DBH)^{0.6183})$

(where a circumflex denotes exponentiation.)

Open grown crown area (m^2) = $(0.25)*(3.141593*cw^2)$

NFI and PSP datasets differed primarily in the fact that PSP plots were fully enumerated, whereas NFI plots were sampled. The sampling method, in conjunction with an assumption of homogeneous spatial diameter distribution, informs the calculation of a sampling weight or *expansion factor* which is used to allow for the possibility that some trees on a given plot were not sampled. The expansion factor is inversely proportional to the prior probability of a given tree's inclusion in the sample, based on the trees diameter class. Each tree in the sample is thus duplicated by a number of times equal to its expansion factor. This duplication is allowed for when calculating plot-level derived variables, e.g. Density, by incorporating the expansion factor into the equations. For example, the estimated number of trees on a plot with a single sampled tree of 8cm is $(12.62/3)^2$. See Figure 8 for an explanation.

	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 8. The NFI sampling scheme at the plot-level. The *expansion factor* for a tree in the *i*th diameter class is $(R_3/R_i)^2$

Diameter increment

The diameter increment model for each cohort was calibrated by fitting to data from the PSP dataset.

$Dinc = \exp(a_0 + a_1 lnDBH + a_2 DBH^{\wedge 2} + a_3 . lnCR + a_4 . lnCCF + a_5 . BAL) + e$

Where a_i, i = 1…5 are coefficients and *e* is a residual that was autocorrelated between measurements on the same tree and independent otherwise. The fitting was done in the Glimmix procedure in SAS, and the model is a GLM with Gaussian variance function and a log link. This is slightly different from Monserud and Sterba (1997), who log-transformed the response, where we log-transform the expected value of *Dinc*, and didn't model autocorrelation.

Where fitting was unsatisfactory, i.e. because of parameter instability or data sparseness, a submodel was selected. A criteria of model selection was that the parameters should be qualitatively similar to those estimated by Monserud and Sterba (1997). In this respect, the fitting of the increment models is better described as model calibration than model selection.

The parameters for the fitted models were:

FGB
E(Dinc) = EXP(-2.8528 + LN(DBH)*1.1729 - 0.00012*DBH^2 + LN(CR)*0.8241 - 0.000015*CCF)
Larch
E(Dinc) = EXP(-2.2969 + LN(DBH)*0.6338 - 0.00096*CCF)
OC
E(Dinc) = EXP(-1.4191 + LN(DBH)*0.554 - 0.00025*DBH^2 + LN(CR)*0.5549 - 0.00052*CCF - 0.00646*BAL)
Pine
E(Dinc) = EXP(-1.3466 + LN(DBH)*0.741 - 0.001*DBH^2 + LN(CR)*0.998 - 0.00066*CCF - 0.00417*BAL)
SGB

E(Dinc) = EXP(-2.5897 + LN(DBH)*0.7534 - 0.00068*DBH^^{2} - 0.0006*CCF - 0.00979*BAL)

Spruce

E(Dinc) = EXP(-1.8628 + LN(DBH)*0.9456 - 0.0005*DBH^2 + LN(CR)*1.1639 - 0.000638*CCF-0.00273*BAL)

Uncertainty:

In this section we look at various measures of the performance for the different models discussed above. The performance measures quoted give rough ideas about how the models perform. It should be noted that performance can be improved somewhat by including plot and site effects but since these are problematic for extrapolation from PSP to NFI, they were omitted from the Dinc model. They were also omitted from within NFI imputation models, by which we mean imputation models calibrated on NFI data, for similar considerations. They were not omitted from PSP-specific models.

We looked at the performance of the various models – DBH-H, CR, Dinc – for the two datasets. Some measures we could have used, that are used by Thurig et al (2005), for example, are *accuracy, precision,* and *excess error,* calculated as follows.

Accuracy : ((Σ(**pred**icted-**obs**erved)/n)*100)/m. Where *m* is E(obs), and *n* is the number of observations.
Precision : SD(pred-obs)
Empirical Excess error (%): ((1-Sec)/Sei)*100. Where *Sec* is the *precision* of the calibration data, and *Sei* the *precision* of the independent data.
Theoretical Excess error : (1/n)[Σ(pred$_{(-1)}$-obs)^2- Σ(pred-obs) ^{2}]. Where pred(-1) is the leave one out prediction error

Note that *empirical excess error* is only viable when doing external validation.

Temesgen and von Gadow (2004), for example, use *root mean squared error* (RMSE) and Bias to evaluate their models.

Bias : (Σ(pred-obs)/n)
RMSE : √(Σ(pred-obs) ^{2}/n-p). Where *p* is the number of parameters in the model.

Another measure is *mean absolute error* (MAE)*.*

MAE : Σ |pred-obs|/n

A certain amount of model selection was done, as noted above, when fitting the models to the data in the first place. This ensures that the fitted models are the most parsimonious to minimise residual error. However, model performance is best evaluated by external validation or, failing that, some cross-validation. We conduct leave-k-out cross validation on the Dinc calibration data. *MAE* and *RMSE* are calculated for each cross-validation dataset replicate. External validation data was only available for the PSP DBH-H model, and that is discussed in another document.

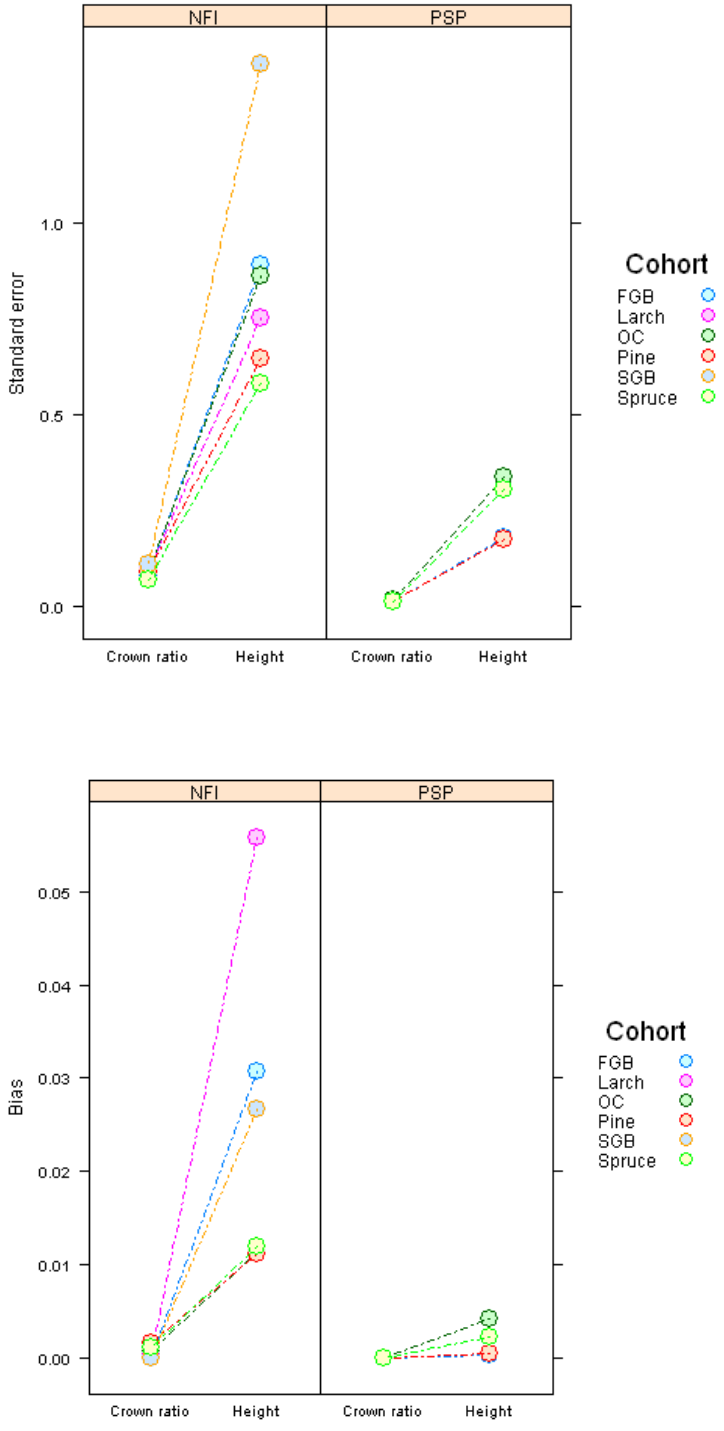

Figure 9. Within-sample *Precision* (upper panel) and *Bias* (lower panel) for imputation. Values are plotted for each dataset, for cohorts, and for models of Height and Crown ratio.

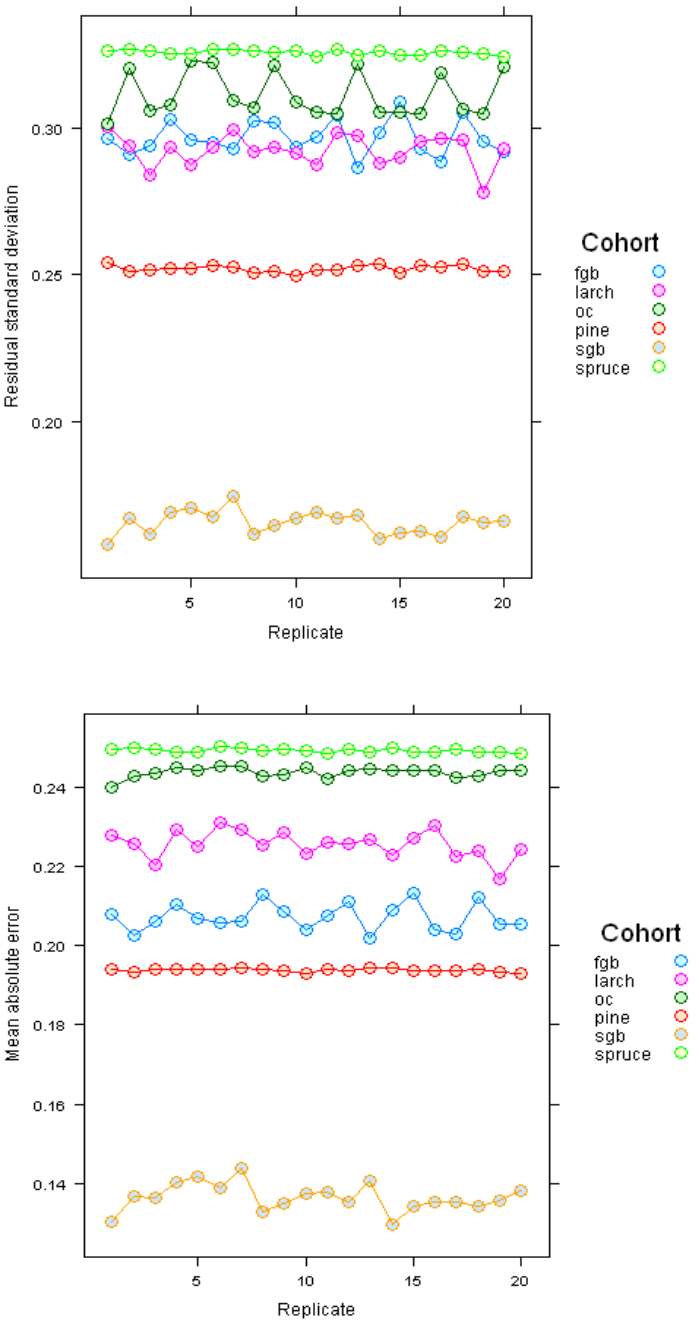

Figure 9. Leave k-out crossvalidation results, *precision* (top) and *mean absolute error* (bottom) for the *Dinc* model. The probability of inclusion in the validation dataset is 0.33. 20 cross-validation replicates are displayed.

Discussion and conclusions

The lines joining the points in Figure 8 are only included to facilitate a comparison between panels. The interpolating lines in Figure 9 are indicative of variability between the different cross-validation runs. This variability is partly a function of data resources, i.e. the number of cases, and the size of the validation

sample as a proportion of the number of cases. The low variability of Pine and Spruce, the cohorts with by far the most number of cases, reflects this.

In Figure 8, the better performance of PSP versus NFI is partly a result of including such blocking effects as site and plot. This idea is also illustrated with more detail in the document on DBH-H modelling.

From Figure 8, bias levels are low for both NFI and PSP. Pine and Spruce, the most important cohorts, are among the top performers. This partly reflects the better data resources for those cohorts.

Taken together, these results can inform uncertainty/sensitivity analyses)to be completed in 2011).

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II) Modelling height increments for small trees

Introduction

Height growth for small trees is a driving developmental force as trees compete for light and vertical growing space. Because of this, the small-tree portion of CARBWARE is a height-growth driven model; height growth is estimated first, and then diameter growth is predicted from height growth (see section B of this appendix E3). Equations used to predict small-tree height increment vary by species, variant, silvicultural practice and site type. Most single tree based models for young growth, generally use the same the same predictors as described for DBH increment models. However, the NFI data set provides little or no information on predictors for young tree height. The development of a H growth model for trees less than 1.3 m to a maximum H of 2.3 to 5.1 m (i.e. the diameter at breast H, DBH) is described here. The model uses a empirical Chapman-Richards approach for different species with sub models for different height index ratios (i.e. mean H over age as proxy's for young stand productivity and site factors).

Methodology

Modelling framework

The model uses a empirical Chapman-Richards approach for different species with sub models for different height index ratios (i.e. mean H over age as proxy's for young stand productivity and site factors).

$$xHinc_{i,j}^{n+1} = \frac{a_1}{1+\exp(-1\times\left[\frac{age^n - a_2}{a_3}\right])} \quad \text{.....(1)}$$

where, *xH* is mean height of all trees in the NFI plot for the $_i$th species and $_j$th H index ratio at the determined age (n+1). The age of the forest (n) is obtained from the NFI stand attribute data. The partial coefficients (*a*) for each species and productivity class and goodness of f

Once the new mean tree H (xH_n+$xHinc_{n+1}$) is computed, the individual tree H is recalculated based on a scaling function:

$$H_{n+1} = \frac{H_n}{xH_n} \times H_n \quad \text{.....(2)}$$

where, H_{n+1} is the individual H of the tree in the plot in the year following the NFI , H_n is the individual H in the year the last NFI was completed (2005), and xH_n is the mean H of trees in the plot in the year the last NFI was completed.

The Productivity class (H over age) categories were defined to match conventional yield class productivity indices (YC*eq*) as described by (Christy and Edwards, 1981). This was derived by comparison of Chapman Richard outputs from each H index ratio (HI) with static age-H tables at ca. 10 to 20 year old crops.

$$YCeq = HI = \min, \left\{YCH_{ij} - xH_{ij}\right\}^2$$

where, YC *eq* is the *HI* equivalent to YC at the lowest least-squares different between the yield table H values (*YCH*) and the predicted mean height (*x*H see equation 1) for the *i*th cohort and *j*th HI.

Selection of tree for H increment model

All trees with no measurable DBH are selected for growth increment using the H model. The CARBWARE model also selects eligible trees to be grown using the H growth model based on cohort-specific threshold DBH values (Table 4). These are derived from analysis of the minimum DBH ranges suitable for the DBH increment model. The transition from the H to DBH increment model is based on the threshold H value which corresponds to the minimum allowable DBH value to be used in the DBH increment model (Table 4). If a tree has a larger corresponding DBH than the threshold value, it is grown using the DBH increment model.

Table 4: Threshold minimum DBH values suitable for use din DBH increment model and corresponding cut-off H values used for H growth in small trees

Cohort	DBH threshold (cm)	Corresponding H (m)
Spruce	4	2.7
Pine	4	5.1
Larch	2	3.6
Other conifers	4	3.1
Slow growing Broadleaves (SGB)	2	4.2
Fast growing Broadleaves (FGB)	2	3.2

Datasets and measure of goodness of fit

We used both the Coillte PSP and NFI individual tree data base to develop H-age curves (range 0.1 to 12 m). Data operations were concerned with assembling datasets of the variables used in the H model, insofar as was feasible.

We looked at the performance of the various models –H-Age for different cohort for the combined datasets. Some measures we could have used, that are used by Thurig et al (2005), for example, are *accuracy, precision,* and *excess error,* calculated as follows.

Accuracy : ((Σ(**pred**icted-**obs**erved)/n)*100)/m. Where *m* is E(obs), and *n* is the number of observations.
Precision : SD(pred-obs)
Empirical Excess error measures could not be performed because there was no external validation data set (Thirig et al., 2005).
Bias : (Σ(pred-obs)/n)
RMSE : $\sqrt{(\Sigma(\text{pred-obs})^2/\text{n-p})}$. Where *p* is the number of parameters in the model.

Results
Fitted model parameters

Table 5 shows the partial coefficients for each species and productivity class for the Chapman-Richards H-Age functions.

Table 5
Spruce cohort

HI range	**YC*eq***				**Precision**	**RMSE**	**Bias**
		a_1	**a_2**	**a_3**			
>1.2	>24	1.02	5.59	2.04	1.8	4.69	0.32
1-1.2	24	1.05	7.05	2.32	1.42	4.23	-0.23
0.8-1	22	0.76	5.98	1.63	1.33	3.21	0.11
0.6-0.8	20	0.66	5.51	1.33	0.66	2.55	0.56
0.5-0.6	18	0.57	5.26	1.12	0.89	1.69	0.45
0.4-0.5	16	0.53	5.35	1.47	1.11	3.66	0.32
0.3-0.4	14	0.48	5.32	0.54	0.74	3.54	0.62
0.2-0.3	12	0.44	6.59	2.20	1.53	4.53	0.24
0.1-0.2	10	0.35	6.93	2.27	0.69	1.77	-0.43
<0.1	<10	0.28	8.02	0.35	1.9	4.23	-0.7

Appendix 1D: CARBWARE stand modification functions

The NFI permanent plots structure is modified at each growth cycle iteration to simulate the losses associated with natural mortality and harvest. This section discusses the development of the CARBWARE modification functions from draft versions for submission to International, peer reviewed Scientific Journals.

I: Mortality models

Introduction

In the general context of forest growth models, and at the most basic level, the tree mortality module's role at each iteration is to classify a particular tree in the dataset as being either dead or alive. This paper approaches this problem in the context of an individual-tree model of mortality, that is both age- and distance-independent. The specific modelling framework within which the mortality module will be applied, is a framework similar to the PrognAus framework, with the goal of estimating annual forest dynamics for Ireland.

Literature review

There are two areas of interest for the literature context of this paper: *tree-mortality* modelling, and *threshold-based* classification. (Note that this paper is not focussed on a survival analysis, as one might perhaps expect, because such models are time-dependent.)

1. *Mortality modelling* in Forest Succession.

Wunder et al. [2006a] compared the use of classical stress-thresholds in mortality modules of forest succession (\gap") models. They conclude that logistica1 regression-based models are superior to stress-threshold models with regard to predicting time of tree death.

Baesens et al. [2003] review threshold-based classifiers in the context of credit-scoring. They examine logistic regression, discriminant analysis, k-nearest neighbour, neural networks and decision trees, advanced kernel-based classification algorithms such as support vector machines and least-squares support vector machines (LS-SVM). They assess performance using the classification accuracy and the area under the receiver operating characteristic curve. They found that both the LS-SVM and neural network classifiers yield a very good performance, but also simple classifiers such as logistic regression and linear discriminant analysis perform very well for credit scoring.

Bigler and Bugmann [2004] introduced a new approach to modelling tree mortality based on different growth patterns of entire tree-ring series. They were interested in predicting time of tree death. In their study, dendrochronological data from *Picea abies* (Norway spruce) in the Swiss Alps were used to calibrate mortality models using logistic regression. They introduced a mortality threshold and classified a tree as dead if its modelled mortality probability curve plotted over time went above that threshold. They ignored autocorrelation at the modelling stage, and applied a jackknife method to correct for the resulting biased variance estimates. They found that the most reliable models were those that included relative growth rate and a short-term growth trend as explanatory variables.

Focussing on the role played by life-history strategies in determining tree mortality Wunder et al. [2008] investigated whether the relationship between growth and mortality divers among tree species and site conditions. This carries on from Monserud [1976] who showed that reduced growth generally accompanies a higher mortality risk. For each of nine species, they modelled mortality probablity as a function of relative basal area increment, tree size and site. They selected the species-specific model with the highest goodness-of-fit and calculated the area under the receiver operating characteristic curve and calibration measures. The discriminatory power as measured by AUC ranged from 0.62 to 0.87. They found that most growth-mortality relationships differed among species and sites, i.e. there is no universal growth-mortality relationship.

It has been noted that a lack of long-term growth/mortality data has made it difficult to evaluate the performance of mortality models. Wunder et al. [2006b] adopt a “virtual ecology" approach to this problem, simulating forests with either of two a priori specified growth-mortality relationships. They simulate different sampling regimes in these virtual forests, thereby generating virtual tree-ring data, forest inventory data, or a combination of both. They compare eight existing or newly developed models of different structural flexibility by their ability to model the growth-mortality relationship in the simulated data, and quantify the deviation from the *a priori* specified growth-mortality relationships with the Kullback-Leibler distance. Of the models they evaluated, the highest accuracies were obtained with tree-ring based models, which required only small (approx. 60) numbers of dead trees. For larger sample sizes (approx

500 dead trees) forest inventory based models were also seen to be accurate. They also showed that exible statistical approaches were superior to less flexible models only for large sample sizes (totally 2000 trees) and that the additional use of Bayesian statistics, model accuracies only when model flexibility was constrained. They also provided guidelines for sufficient sampling schemes in real forests.
In the PrognAus framework, Monserud and Sterba [1999] modelled mortality in Austrian forests for six major species based on 5-year re-measurements of the permanent plot network of the Austrian National Forest Inventory. Their general results, varying slightly between species, was that inverse of tree diameter, crown ratio and BAL were respectively the three most closely correlated factors in their model with 5-year mortality rates. They compared mortality rates across tree diameter class, thereby identifying a classic U-shape in mortality rates as diameter class increased. They modelled mortality rates rather than individual tree mortality probability, and validated the model with the chi-square statistic calculated between observed and estimated. Because the explanatory variables in their model were measured on the scale of the individual tree, they were able to calculate the classification success rate using the complement of the overall proportion
of mortality (i.e., approx 93%, although it is not clear from the text) as the threshold. On this basis, their model correctly classifieded between 81 and 92%, of live trees, and between 25 and 44%, of dead trees. However, their treatment of the threshold is very brief, and may not be a typical interpretation, e.g. in their interpretation, a tree is classified as dead if the threshold exceeds the modelled probability. Also, they derive a total correct classification accuracy of 86%.

Materials and Methods

We fitted logistic regression models to the growth dataset. We investigated model performance in the case of separate models for each cohort. (Principal issue here was the lack of data for some cohorts). The response variable was a binary indicator of mortality (arbitrarily, 1 = tree dead at time of DBH measurement, 0 = tree alive). We only included trees whose cause of death was natural mortality, e.g. such causes as windblown, diseased, were excluded. Explanatory variables were as such that were selected by Monserud and Sterba [1999] {DBH and transformations thereof, CR, BAL, CCF}, but we also investigated relative growth indicators that Bigler and Bugmann [2004] noted as being useful correlates. Site and plot effects were modelled as random, and consecutive observations on the same tree were modelled as being correlated. Conditional on this correlation structure the fixed effects parameters were selected by backward selection starting with the candidate set of covariates just listed.
Models were fitted by maximum likelihood and individual fixed effects were identified as non-significant on the basis of asymptotic Wald-tests. This was done for each cohort separately. Performance of candidate models was then evaluated by cross-validation and external validation (comparing fitted to observed mortality in NFI dataset) and with threshold-based classification tools like the ROC and ROL curves and related measures and hypothesis tests. Cross-validation was done on a leave-k out basis, where the data \left-out" was selected at random. Up to twenty independent cross-validation runs were performed, and up to 33% of the data was left-out as cross-validation data for each run.
Other performance measures were consulted, and the ROC convex hull played a role in our chosen classifier. We used threshold-averaging to investigate the performance of the classifier in cross-validation and bootstrap scenarios. We derived confidence bands for the ROC curve of the chosen classifier following the approach of Macskassy et al. [2005]. (Note, the authors have also developed techniques for point interval estimation also, the reference appearing in that paper.)

Performance measures in ROC space and their role in uncertainty analysis

The AUC of the ROC curve is the estimated probability that the classifier will give a higher score to positive cases than negative cases. (In our application, that the estimated probability of mortality is higher for dead trees than live trees.) We envisage that an uncertainty analysis of the forest growth model of which the mortality classifier is a component part could utilise this probability and its standard error in monte-carlo simulation assessments of overall uncertainty and sensitivity.
The AUC is equivalent to the Mann-Whitney U-statistic, and methods for comparing AUCs have been developed as a result, e.g. Heagerty et al. [2000]. The principal complicating factor here is the underlying correlation structure of the comparison, which can be influenced by details pertaining to the derivation of the classification forecasts, the setup of the calibration datasets, or whether the forecasts are clustered in someway, e.g. DeLong et al. [1988], Obuchowski [1997], Heagerty et al. [2000], Mason and Graham [2002].

The convex hull of a classifier, or group of classifiers, in ROC space, can be seen as the optimal attainable classification performance. Fawcett [2006] notes that candidate classifiers that do not attain the convex hull can be discarded, on the grounds that a better classifier in ROC space exists. He suggests a method for interpolating between candidate classifiers to better approach the limit of performance estimated by the convex hull based on mis-classification costs and the prior class distribution.
When comparing ROC curves, per se, a complicating factor when it is of interest to compare different classifiers crops up if the classifiers in question are of a different \class", e.g. a probabilistic classifier versus a discrete classifier, or, more generally, comparisons across model classes, whose scoring systems are incommensurate Fawcett [2006].

Datasets

Permanent Sample Plot

The mortality model is calibrated on data extracted from the permanent sample plot record system of Coillte Teoranta (the Irish Forestry Board state commercial forestry company). Broad and Lynch [2006b] provide details of the dataset in the context of modelling plot volume. The database consists of records of many silvicultural and thinning trials. These longitudinal trials were established from the 1950s onwards, and were initially established as replicated and blocked experimental designs Broad and Lynch [2006a].
Although there are several categories of disease or mortality causes in the PSP database {including, Windblown, Uprooted, Diseased, Broken and Dead}, we modelled only the binary response Dead/Alive for the initial model. In this way, after derived variables { basal area, plot density, etc. {were calculated, only data points that could be classified as Dead/Alive, were kept in the calibration dataset

National Forest Inventory Plot data

We validated the ROC curve for the chosen model on the NFI data. In the NFI sample, the probability that a tree's status as dead or alive will be recorded { more generally, the probability that any feature of the tree is measured { is a function of its diameter class at the time of survey, and its distance from the centre of the plot. The expansion factor concept is a weight that varies between each tree in the dataset that estimates the prior probability of the tree's inclusion in the dataset. Figure 10 shows that trees of three diameter classes are only recorded if they are observed within a certain distance from the plot centre. The expansion factor we use, and that used by the NFI, assumes a random distribution for tree diameter in the plot. Because of that assumption, the weight assigned to a tree in the ith diameter class is:

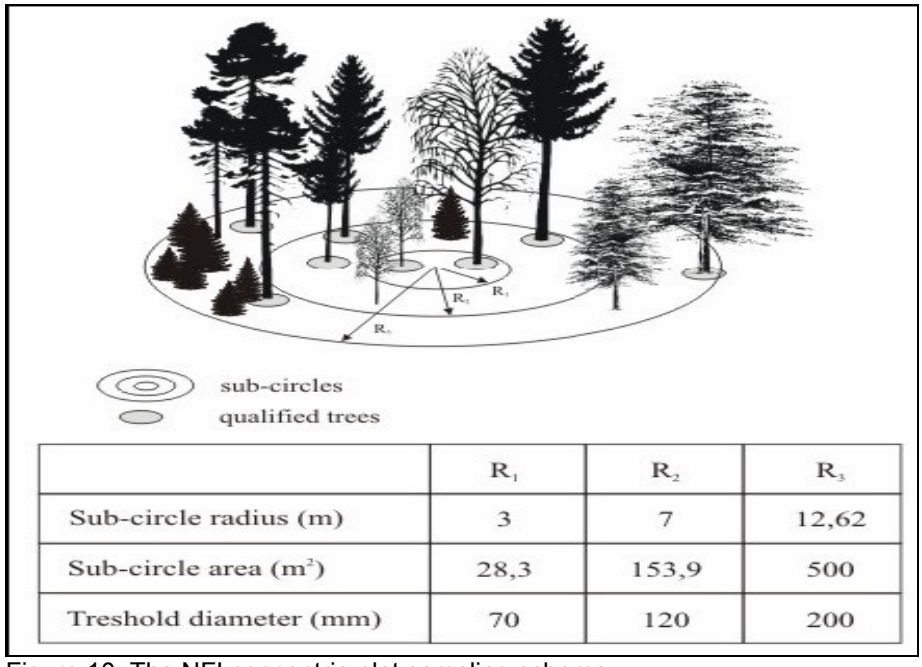
$$\frac{R_3^2}{R_i^2} \quad \text{.....(1)}$$

where Ri denotes the radius of the concentric circle associated with the ith diameter class.

In practice, the expansion factor, or weight, is used to estimate plot-level features, e.g. basal area. In such calculations, we estimate the number of trees of the ith diameter class that were not included in the sample by $\frac{R_3^2}{R_i^2}$ * ni, where ni is the number of trees of the ith class that are included in the sample. The expansion factor therefore defines the relationship between each included tree and the estimated number of trees of the same class that were not included (Equation 2).

$$n_{ij} \times EF_{ij} = \hat{N}_{ij} \quad \text{..... (2)}$$

where n_{ij} _ EF_{ij} is the product of the expansion factor for the *j* th tree in the *I* th class, and $\check{N}_{ij}$ is the corresponding estimate. In the terminology of the NFI, the RHS of Equation 2 is the representative tree number. With minor and obvious changes to the equation, we can calculate other tree-level estimates, including representative basal area, and individual-tree estimates can be aggregated for the entire plot to give plot-level estimates, including representative density.



	R_1	R_2	R_3
Sub-circle radius (m)	3	7	12,62
Sub-circle area (m^2)	28,3	153,9	500
Treshold diameter (mm)	70	120	200

Figure 10: The NFI concentric-plot sampling schema.

The question we have to address in the current paper is whether we can arrive at a sensible definition of representative mortality. At issue is how to derive a binary individual-tree-level mortality rule based on information in the NFI dataset, given the fact that there is missing information due to the sampling scheme. With this in mind, Figure 2 classifies all dead trees in the PSP database by cohort, and describes the empirical distribution of diameter classes conditional on mortality status. (We have included the diameter class (0,7] for completeness, even though there is no equivalent in the NFI dataset.) Note that the left-hand column is very similar to the unconditional distribution of diameter classes, so it does not need to be displayed. On those grounds, a comparison of the columns of Figure 2 shows the dramatic extent to which the chance of mortality declines if a tree does not die while in the lowest diameter class. For example, the global fraction of trees in the Spruce cohort in the lowest diameter class is very small, but this class represents 50% of dead trees in the cohort. Similarly for Pine, OC and FGB.
The right-hand column of Figure 2, at least for the cohorts with enough observations, suggests a way to make the operation of a binary mortality rule more accurate in the context of the NFI sampling scheme. The basic idea would be to use the column heights as weights in a finite mixture function whose components would be the outcome of the mortality rule. Rather than reducing the expansion factor by one unit when death is predicted (which, we can show, can lead to an unrealistically height global mortality rate), the actual reduction would be a function of the weight for the given diameter class. This method could be stochastic or deterministic. Other information might be used to inform the values of the weights, including a forester's rule of thumb about global mortality (i.e., _ 6%), or information from the NFI or a meta-analysis.
A similar approach would be to mix the outcome of the mortality rule with the diameter class mortality weights. It might be possible to iteratively tune the weights and/or the rule's cut-off parameter.

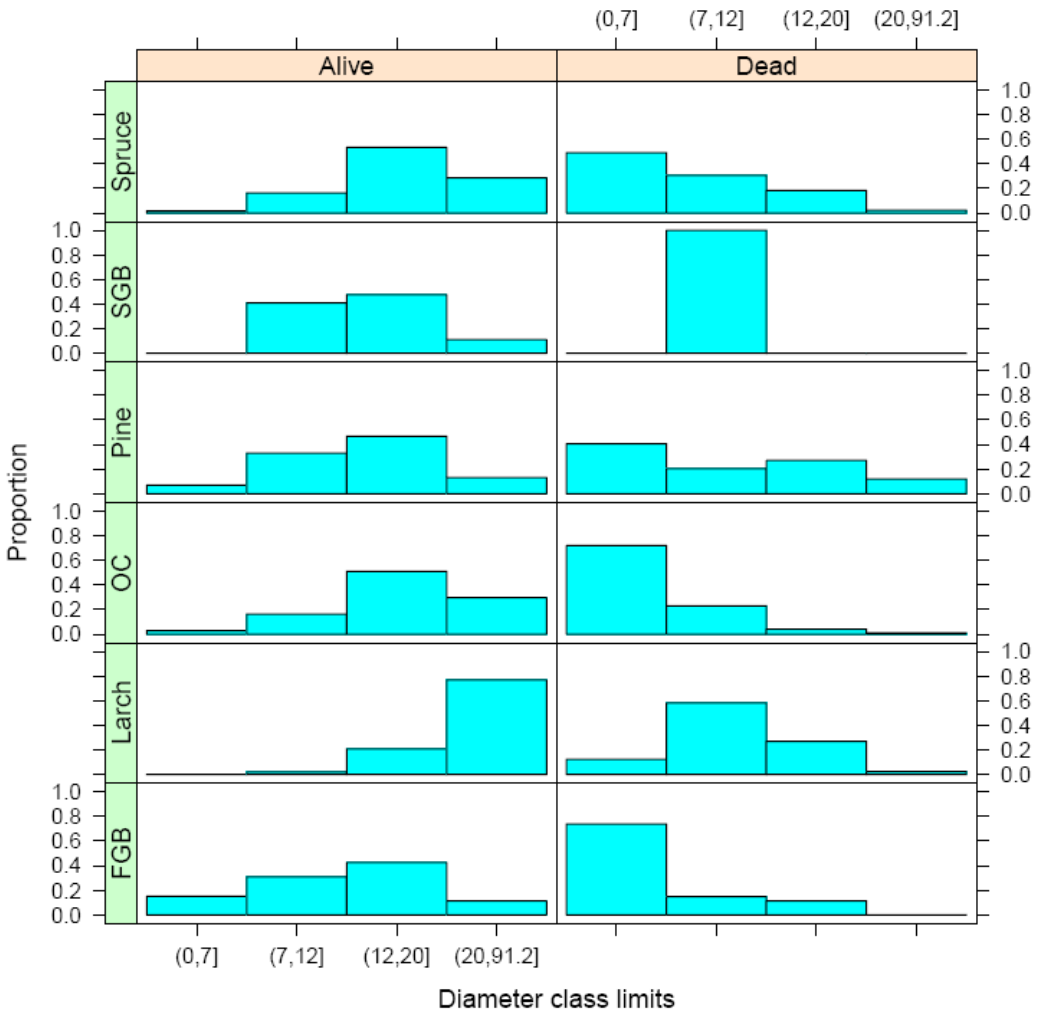


Figure 11: The empirical distribution in the PSP dataset of diameter classes of dead/alive trees classified by cohorts.

Results

*Candidate model Number 1*Candidate model 1 was a fixed effects model. A logistic GLM was fitted in Glimmix. The _fixed effects were DBH, BAL, and

RelDiamInc $\left(\frac{growth(t-t-1)}{DBH(t)}\right)$

Part of the reason for looking at this model was that it was not subject to additional uncertainty due to imputation of missing X data, as would have been the case with the model put forward by Monserud and Sterba [1999], which also conditioned mortality on CR, a variable that was not measured on every tree in our dataset.

There are several points of interest to the results of this model fitting:

1. The characteristics of the parameters.
2. The cross-validation exercise.
3. The out-of-sample/deployment performance. E.g. how well the model described NFI mortality.

Estimated parameters Candidate Model 1 (Used in CARBWARE models)
The fitted parameters and their standard errors are presented in Table 4. We supply parameter estimates for cohort-wise fits and the fit to the entire dataset, with no cohort-effect parameter.
Table 4: Candidate model 1 parameters
(Fast-growing broadleaves cohort).

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	-2.9295	0.1510	11784	-19.41	0.0001
DBH	-0.4307	0.02508	11784	-17.17	0.0001
BAL	0.06816	0.004384	11784	15.55	0.0001
RelDiamInc	-1.6783	1.2147	11784	-1.38	0.1671

(Larch cohort)

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	3.0526	0.1691	6544	18.06	0.0001
DBH	-0.4373	0.01276	6544	-34.27	0.0001
BAL	0.05688	0.003066	6544	18.56	0.0001
RelDiamInc	-14.7793	2.5794	6544	-5.73	0.0001

Other conifers

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	4.3636	0.1090	21239	40.02	0.0001
DBH	-0.8384	0.01447	21239	-57.95	0.0001
BAL	0.05970	0.002078	21239	28.72	0.0001
RelDiamInc	-29.2957	1.0322	21239	-28.38	0.0001

Pine cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	2.3952	0.04531	187E3	52.86	0.0001
DBH	-0.8127	0.007225	187E3	-112.49	0.0001
BAL	0.08083	0.000999	187E3	80.91	0.0001
RelDiamInc	-23.0015	0.3995	187E3	-57.57	0.0001

Slow growing broadleaves

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	29.6029	7.1305	1027	4.15	0.0001
DBH	-2.1970	0.4873	1027	-4.51	0.0001
BAL	-0.1225	0.01754	1027	-6.98	0.0001
RelDiamInc	-2199.90	521.36	1027	-4.22	0.0001

Spruce cohort

Parameter	Estimate	s.e.	df	Wald statistic	Wald p-value
Intercept	1.2286	0.02747	298E3	44.72	0.0001
DBH	-0.6640	0.003840	298E3	-172.93	0.0001
BAL	0.05051	0.000529	298E3	95.57	0.0001
RelDiamInc	-13.0524	0.2544	298E3	-51.30	0.0001

Candidate Model 2

The fixed effects in Candidate model 2 were those in Monserud and Sterba [1999], and diameter increment as a proportion of diameter (RelDiamInc).

Cross-validation and deployment performance

We performed plot-wise and case-wise leave k-out cross-validation of the chosen models. The case-wise deletion algorithm was very slow for the Pine and Spruce cohorts, in which case we opted to use only plot-wise deletion. The algorithm selected plots for deletion from the fitting dataset using a Bernoulli mechanism with parameter p, which we sometimes changed depending on the number of plots in the cohort dataset. Details are provided with each graphical representation of the results in Figures below. Twenty \leave-outs"were performed and the variability in these twenty runs is represented by the dotted curves.

We estimated the ROC curve for each cohort model's out-of-sample performance by comparing model predictions with the actual NFI mortality data (Figures 13). The cross-validation and deployment performance plots are presented pair-wise in the Figures below.

In all cased model candidate outperformed candidate based on false positives and fit. For example we show the results for Fast growing cohorts in Figure 13.

Note that Slow-growing broadleaves cohort did not have enough data for the cross-validation to be feasible, so the ROC curve for that cohort depicts in-sample performance.

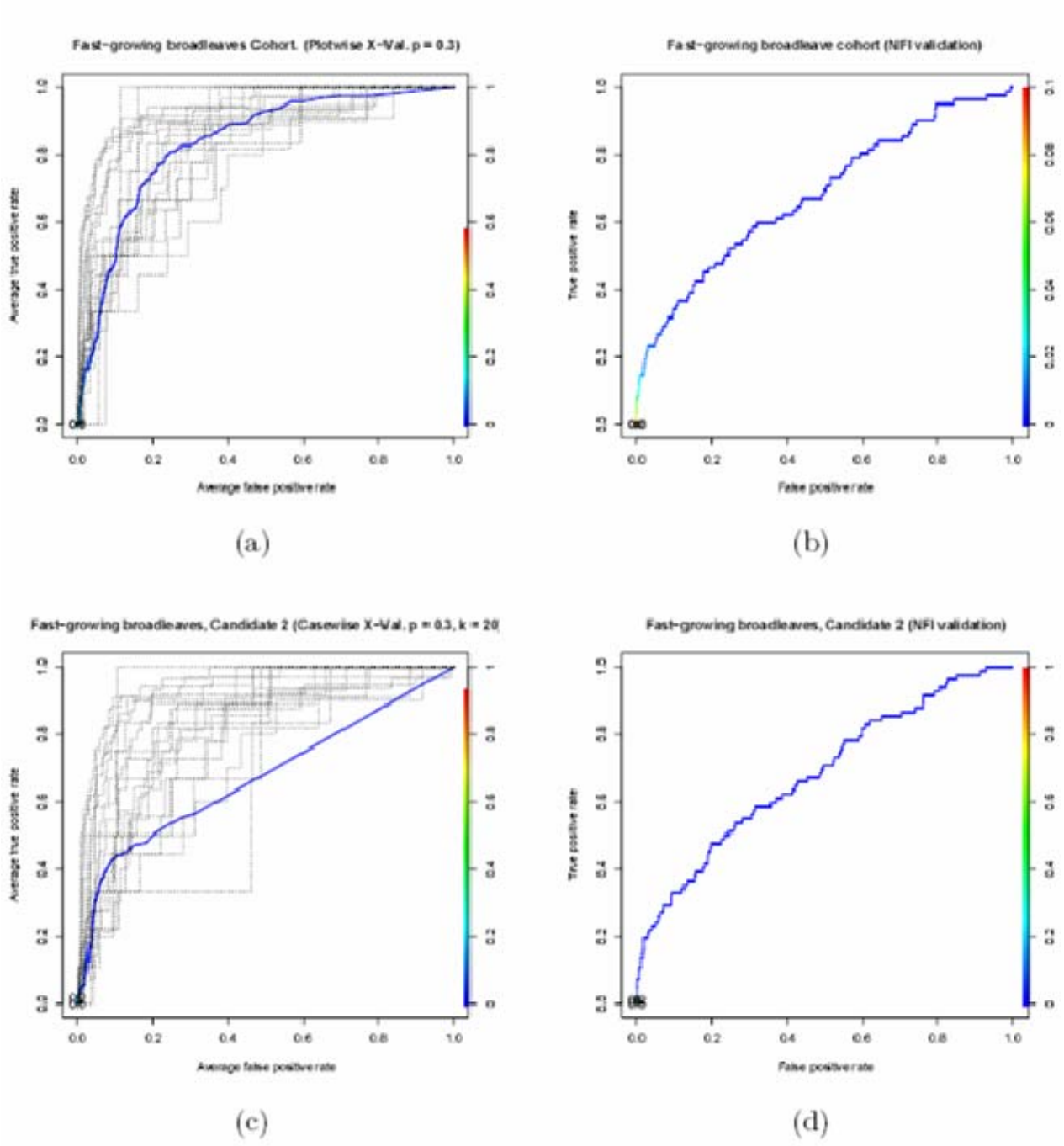


Figure 13: The Receiver operating characteristic curve for Candidate model 1 (panels (a),(b)) and model 2 (panel (c),(d)) in the Fast-growing broadleaves cohort. 20-fold cross-validation plotwise with average leave-out probability p = 0.3. Curves for each cross-validation run and a threshold-averaged curve are shown.

Models fitted to NFI data

When fitting models to the NFI data we used backward elimination, starting with the parameters in the Monserud and Sterba [1999] model. Relative diameter was not used, because the dataset is cross-sectional. In Figure 14 we present an example of the out-of-sample performance (i.e. their performance in predicting NFI data) of the two PSP-calibrated models, and the in-sample performance of the NFI-calibrated model.

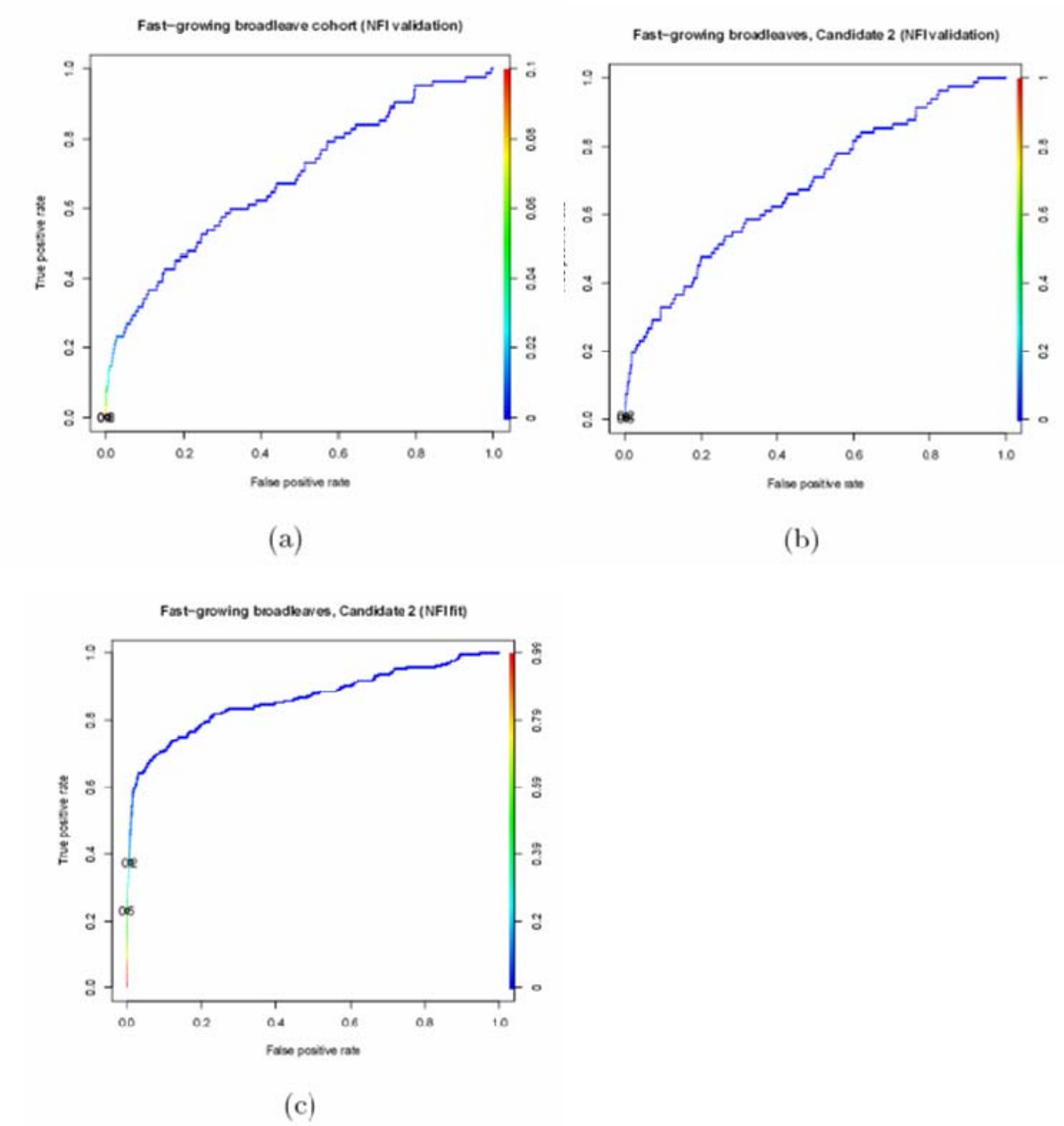


Figure 14: The Receiver operating characteristic curve for Fast-growing broadleaves cohort Candidate models 1 and 2 fitted on PSP, and for the NFI-fitted model.

The selected CARBWARE models based on NFI data fits
Fast-growing broadleaves cohort

$$Pmort = IL(12.93 + 0.068 \times BAL - 2.868 \times CR - 0.962 \times DBH - 72.28 \times \frac{1}{DBH} + 0.009 \times DBH^2$$

Larch cohort

$$Pmort = IL(-4.9266 + 0.04273 \times DBH)$$

Other conifers

$$Pmort = IL(-4.5226 + 0.067 \times BAL - 6.05 \times CR + 0.066 \times DBH)$$

Pine cohort

$$Pmort = IL(2.395 + 0.0408 \times BAL - 3.0036 \times CR - 0.2263 \times DBH - 24.21 \times \frac{1}{DBH})$$

Slow growing broadleaves

$$Pmort = IL(15.78 + 0.0109 \times BAL - 2.2807 \times CR - 0.771 \times DBH - 94.002 \times \frac{1}{DBH} + 0.00449 \times DBH^2$$

Spruce cohort

$$Pmort = IL(6.8976 + 0.0912 \times BAL - 21.3795 \times CR - 0.8287 \times DBH - 49.15 \times \frac{1}{DBH} + 0.008 \times DBH^2$$

Where (0 < Pmort < 1) is the probability the tree is dead. We map then this estimated probabiilty onto the binary (Dead, Alive) outcome using a cutoff, which may differ between cohorts. More details on this is give elsewhere. IL(.) is the inverse logit, e.g. IL(x) = exp(x)/(1+exp(x)).

Choosing the operational cut-off

To identify a cut-off level to use for the mortality probability estimate, we plotted the True positive rate (TPR) and (FPR) on the same axis versus the cut-off (e.g. Figure 15). In forest mortality, the number of positive cases (dead trees) is usually greatly outnumbered by the number of negative cases. This suggests that, all mis-classification costs being equal, the cut-off should be chosen with a view to keeping as small as feasible the rate of false positives predicted by the resulting rule, even though the rate of true positives is reduced as an unavoidable consequence. When combining individual cohort results to make an aggregate prediction the issue of false positive rate is of particular importance for large cohorts, because they have a greater weight in the aggregate estimate. In Figure 15 we represent an FPR of not greater than 0.001 with a blue vertical line, and an FPR of not greater than 0.01 with a green vertical line, to illustrate the trade-off involved in each particular case.

Table 8: Formulae for some standard performance measures used in the text. Note TP, TN, FP, and FN are the numbers of true positives, true negatives, false positives and false negatives, which are tallied by comparing the predictions with the data.

Performance Measure	Formula
Accuracy	$\frac{TP+TN}{TP+FP+TN+FN}$
Rate of positive predictions	$\frac{TP+FP}{TP+FP+TN+FN}$
Correlation Coefficient	$\frac{(TP.TN)-(FP.FN)}{\sqrt{(TP+FN).(TN+FP).(TP+FP).(TN+FN)}}$

Figures 16 illustrate some other considerations for choosing cut-off points. accuracy, rate of positive predictions and a correlation coefficient are plotted for a range of cut-offs (cf. Table 8 for definitions of terms).

The graphs illustrate why the accuracy measure should not be used in isolation when choosing a cut-off. For example, in Figure 16 a high accuracy is obtained despite the correlation coefficient indicating that the correlation between correct predictions and the data is worse than random, i.e. a negative correlation coefficient. Some performance measure formulas are given
in Table 8. These measures and others are described in Sing et al. [2005].

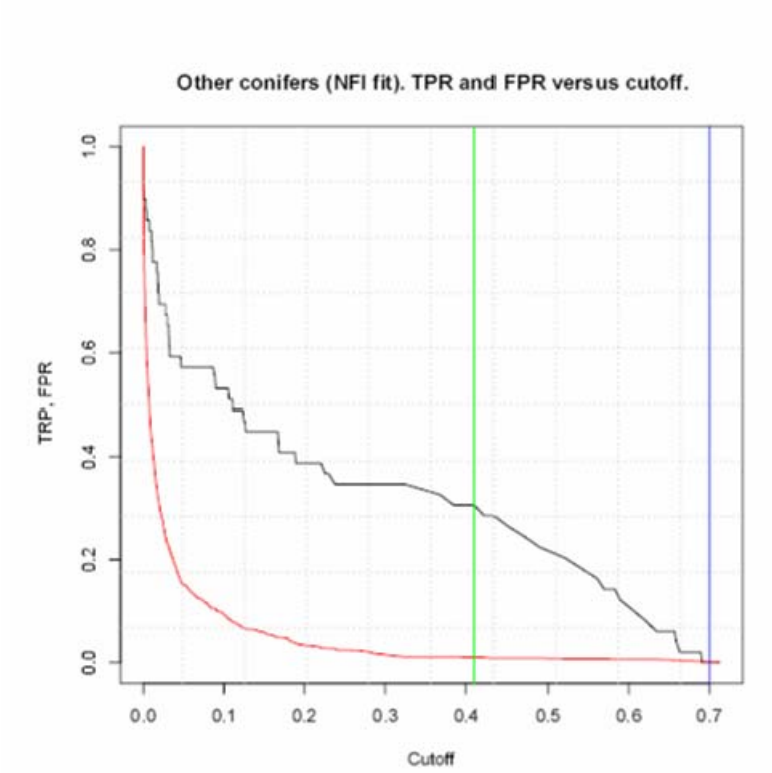
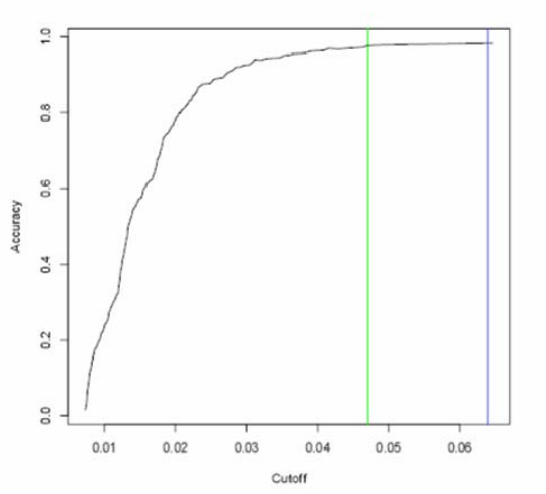
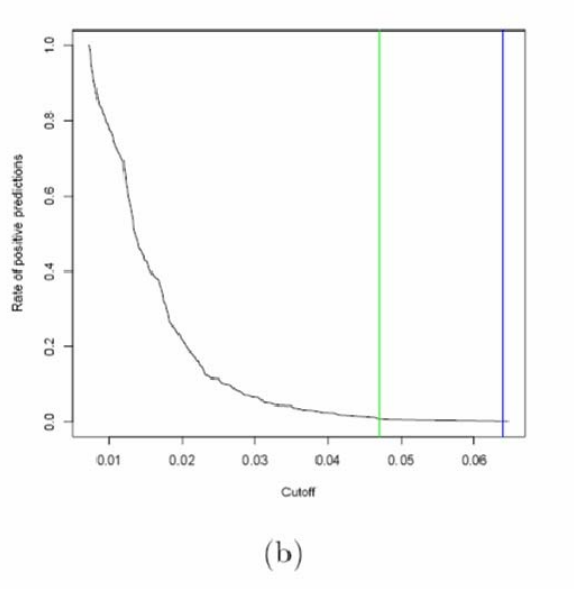


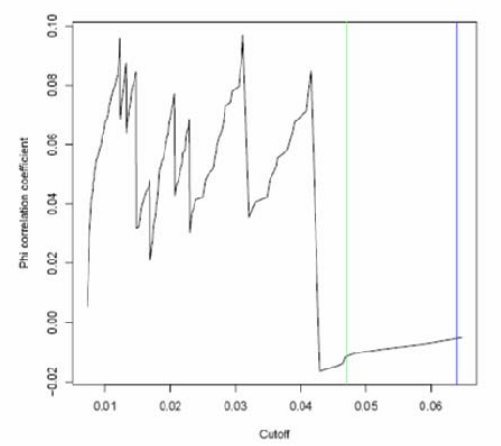
Figure 15: TPR (Black) and FPR (Red) versus cut-off for Fast-growing broadleaves. The vertical green line shows the cut-of where FPR < 0.01, the blue vertical line shows the cut-off where FPR< 0.001.



(a)



(b)



(c)

Figure 16: Illustrating some other performance measures of the NFI-calibrated model for the Larch cohort across the cut-off range and in particular the 0.01 (green vertical) and 0.001(blue vertical) cut-off points.

Discussion

In binary classification, a common approach is to visualise the parameterised curve described by plotting two performance measures as a parametric curve parameterised by the threshold value. Comparing models based on classification and mis-classification rate (precision, recall, etc.) make more sense when there is some hierarchy of misclassification errors. That is, that we
can quantify the relative importance of gains from correct classification and losses from incorrect classification. Such a loss function is particularly useful when the number of objects to be classified is not equal, because then the trade-off curves are much more likely to be nonlinear and the concept of trade-off between competing performance measures is not easy to understand. The problem is how to specify losses/gains, in other words, how to quantify Trade-off, how to measure gains and losses in the same units so a net trade-off can be calculated. Otherwise, it is not always clear, even for commonly presented parameterised curves, in what sense the trade-off is occurring, particularly when a “good" classifier, e.g.

one that exhibits desirable tendencies in threshold-space, can *a priori* exhibit a number of different “shapes" when presented as a “trade-off" curve.
For example, the class ROC trade-off curve has *a priori* a sense in which a classifier is good or bad. This is when the majority of the ROC curve lies below the line of equality. However, the precision-recall curve is not so easily understood. We know that the best classifier from a group is the one with the largest area between the curve and the line of equality. However, because the value of the precision at zero threshold is a function of the number of objects in each class to be classified, it is possible to have a “good" classifier for which that area is zero. However, such a classifier is probably not statistically better than the naive, 50:50 classifier. We propose that for a classifier to be demonstrably better than the naive classifier, it should at the minimum describe a positive region between the curve and the line of equality. We conclude that the precision-recall curve does not describe a trade-off, and that in fact, a trade-off should have a point of equilibrium and the gains and losses should be incurred when the threshold moves from that point in either direction. In other words, the gains and losses as quantified by the two performance measures should be negatively correlated, for the parameterised graph to truly describe a trade-off. The precision-recall performance measures, for example, are positively correlated (both have TP in the numerator), and so their parameterised curve representation does not describe a true trade-off situation in every region of threshold space. If we overlay the two graphs with precision and recall on the y and y' axes, and threshold on the x axis, we can see more clearly where a true trade-off may occur. It is likely that should a true trade-off occur, that the region between the parameterised curve and the line of equality will have to be positive. As external corroboration, DeLong et al. [1988] note that the cost or loss function is essential to deciding the optimal cutpoint/threshold for a ROC curve. In summary, there are therefore two issues: comparing classifiers and, given a classifier, choosing a cut-off point.
This latter can only be done in conjunction with some kind of loss function describing costs of the different types of classification error. The kind of classifier we are using, based on multiple correlation/regression, and therefore wholly empirical, is easier to select than other types of classifier. We can use model selection criteria based on correlation/regression, or minimization of errors, or some other abstract modelling concepts. Then, the classifier selected, we can choose the cut-off. In what we call mechanistic classifiers, such as described in Martin-Davila et al. [2005], where the classifier is predicated first and foremost on an understood pathway, not naive correlation, the threshold has a physical dimension, and the choice of cut-off has a defined purpose in a physical system. Note that a logistic regression with a single explanatory variable can be made to fit such a schema. In fact, it might be possible to define a convex hull of the multiple explanatory variables to take the place of single-variable classifier in that schema. Also, some variables might be better at defining the threshold than others and this can also be examined. A convex hull defined by cut-off points in each explanatory variable might be envisaged to play the role of a kind of “syncretized" cut-off point. In such an instance, it would be relevant to assess the cross-correlations among the explanatory variables.

Conclusions

We set out to determine a logistic regression model of mortality that could be used to describe mortality in the NFI data. This was the ultimate goal of the model. We investigated the possibility of calibrating this model on the permanent sample plot longitudinal data but found that we could improve the result be simply calibrating the parameters on the NFI data alone. In the absence of a mis-classification cost function we chose the cut-off for transforming predictions on the logit scale to the binary (dead, alive) scale based on the false positive rate (the rate at which the model predicted mortality incorrectly). Specifically, we chose the cut-off to keep this as small as reasonably possible.

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II: Other modifications in the growth simulator

Thinning/Harvest

We assume that all thinning occur randomly. Random thinning can be implemented on an individual plot level. The CARBWARE user sets a basal area (BA) to be removes as stipulated in the harvest activity data (in the '**Eventstable**') so thinning of trees are selected at random from the plot until this target BA is achieved. The thinned or harvested trees in a given plot are removed from the growth database and populated in a modifier table within the CarwKP_08 database. These data are they called up in the allocation module (Appendix E2 and section 111.2.3).
Although it is common practice that clear felled stands are replanted within 2 years, the CARBWARE model does no re-populate clear felled plots due to uncertainty of re-establishment success and species choice. This is a conservative approach and is consistent with the rules applied, which differentiate between deforestation and clear fell with re-establishment (see section 11.4.2)

Appendix 1E. The allocation module

The total carbon stock changes for a given forest category is calculated as the sum of the changes in the above-ground biomass (AB), below-ground biomass (BB), Litter (Li), deadwood (DW) and soil (So) carbon pools (Equation 2.3 in Chapter 2 of the 2006 IPCC guidelines):

$$\Delta C_{lu} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{Li} + \Delta C_{Dw} + \Delta C_{So} \quad \text{.....(1)}$$

Biomass estimates include biomass for trees only, non-tree vegetation is assumed to be in steady state following canopy closure. Below ground biomass includes all roots up to a diameter of 5cm. Litter is defined as deadwood with a diameter of less than 7cm. This includes abscised needles and leaves. The dead wood pool included all lying and standing deadwood, dead roots and stumps with a diameter greater than 7cm. organic and mineral/organic soils are reported (see section 11.3.1.2)

Biomass stock change

Biomass carbon stock changes are calculated using a tier 3 gain and loss method, corresponding to the process-based approach given by equation 2.4 in Chapter 2 of the 2006 IPCC guidelines, which gives the net carbon stock change as the difference between carbon gains and carbon losses

$$\Delta C = \Delta C_G - \Delta C_L \quad \text{.....(2)}$$

The biomass carbon gains (ΔC_G) for both above-ground biomass (AB) and below-ground biomass (BG) are calculated for each forest category i, listed in table 11.2 using

$$\Delta C_G = \sum_i \left(A_i \times GTOTAL_i \times CF \right) \quad \text{.....(3)}$$

where A_i is the area of the forest category, $GTOTAL_i$ is the biomass change (t dm/ha.yr) in area A_i and CF is the carbon fraction of biomass dry matter, which is taken as 50 percent for all carbon pools (Black et al., 2007). $GTOTAL_i$ is derived from the sum of all living individual tree components (i.e. AB or BB) within the plot, for example:

$$GTOTAL_{AG} = AG_n - AG_{n-1} \quad \text{.....(4)}$$

where n is the year of inventory. The GTOTAL value for each NFI permanent sample plot is multiplied by a factor (e.g. 20 for 0.05ha plots) to scale the plot measurement up to 1 ha (specified in the ***lookup table***). The AG and BG of all trees were calculated using biomass algorithms for different species cohorts based on national research information (Appendix A), where diameter at breast height (DBH) and tree height (H) are used as dependent variables. These variables are found intermediate input tables in the I**ncrementDB** (e.g. ***Project_t0*** or **Project_T1+n**, see Figure 2 section 3). The stocking (number of trees in a plot) is adjusted after every growth simulation cycle using the stand modification module (Figure 2), which removes trees based on natural mortality models and harvest activity data (Appendix E4).

Biomass carbon losses from the above-ground biomass pool ($\Delta C_{L(AB)}$) were calculated based on harvest (L_{timber}), harvest residue (L_{HR}), litter fall (L_{LF}) and above-ground losses due to mortality ($L_{mort(AB)}$):

$$\Delta C_{L(AB)} = L_{timber} + L_{HR} + L_{LF} + L_{mort(AB)} \quad \text{.....(5)}$$

L_{timber} is calculated based on the above-ground biomass removed from harvest, simulated in the stand modification module (Section 3 & figure 2). The **allocation** algorithms for timber based on AB, H or DBH were derived from national research information (see Appendix A). L_{HR} includes the harvest residue representing all stems and branches with a DBH less than 7cm and litter left on site after timber is removed:

$$L_{HR} = AG - L_{timber} \quad \text{.....(6)}$$

L_{LF} reflects the transfer of carbon from the AG pool to the litter pool (listed in the ***Project litter table*** in the **IncrementDB**). This is calculated in the **allocation module** (Section 3, Figure 2), based on nationally derived leaf/needle biomass (LB) and the foliage turn over rates (F_t) (Tobin et al., 2006):

$$L_{LF} = LB \times F_t \quad \text{.....(7)}$$

Allometric equations and coefficients used for the calculation of LB for different species cohorts, with either AG or DBH as dependent variables, are shown in Appendix A. The F_t rate was assumed to be 5 years (i.e. F_t = 0.2) for conifer crops and 1 year for broadleaf crops (Tobin et al., 2006). The mortality of trees is based on nationally derived single tree mortality models (Appendix D). The above-ground biomass loss from mortality ($L_{mort(AB)}$) was calculated using DBH and H as dependent variables in biomass algorithms (Appendix A).

Biomass carbon losses from the below-ground biomass pool ($\Delta C_{L(BG)}$) were calculated as the sum of losses due to death of roots after harvest (L_{HRroot}), natural mortality of roots ($L_{mort(BB)}$) and root death following fire (L_{fire}):

$$\Delta C_{L(BB)} = L_{HRroot} + L_{mort(BB)} \quad \text{.....(8)}$$

L_{HRroot} is the root biomass transferred to the deadwood pool following harvest. All roots are assumed to die and decompose following harvest. The mortality of roots is assumed to follow that for trees, as estimated from nationally derived single tree mortality models (Appendix D). The below-ground biomass loss from mortality ($L_{mort(BB)}$) was calculated using above-ground and total biomass algorithms (Appendix A).

Litter Carbon Stock Change (***Project_Litter tables***)

Net litter stock change (ΔC_{Li}) was calculated based on litter inputs (gains) due to litterfall (L_{LF}), as given by equation 7, harvest residue litter input (L_{HR}) in equation 6, mortality litter inputs (M_{li}), and losses associated with decomposition of the litter pool (L_{decomp}):

$$\Delta C_{Li} = (L_{LF} + L_{HR} + M_{Li}) - L_{decomp} \quad \text{.....(9)}$$

where
M_{Li} is the input to the litter pool from natural mortality (i.e. all aboveground dead material with a diameter less than 7 cm). This is derived from the $L_{mort(AB)}$ minus the timber fraction of the new dead pool ($L_{mort(tim)}$):

$$M_{Li} = L_{mort(AG)} - L_{mort(tim)} \quad \text{.....(10)}$$

The decomposition losses of the new input litter (L_{decomp}) and existing litter pool (L_{old}) are calculated using decomposition factors of 0.14 taken from national research (Saiz et al. 2007; Black et al. 2009b):

$$L_{decomp} = 1 - \left[\sum [L_{LF}, L_{HR}, M_{Li}, L_{old}]^{-D_{Lt} \times t}\right] \quad \text{.....(11)}$$

$$L_{old} = \sum [\{(L_{LF}, L_{HR}, M_{Li})_{n-1,n-2,n-x}), L_{ini}\}]^{-D_{LI} \times t-1} \quad \text{.....(12)}$$

where, L_{ini} is the initial litter pool estimate input by the user in the ***lookup table*** in the **Carbw..mdb.** The remaining litter from the newly input litter, harvest residue and mortality pools from the previous years (n-1, n-2 etc) were accumulated following decomposition.

Deadwood Carbon Stock Change (Project_deadwood table)
Net deadwood stock changes (ΔC_{DW}□□) were derived from carbon inputs associated with timber extraction residue (L_{tr}), timber from mortality (M_{timber}), dead roots from mortality ($L_{mort(BG)}$), roots from harvest (L_{HRroot}) and carbon loss due to decomposition of the new and previously existing deadwood pool (D_{DW}):

$$\Delta C_{DW} = (L_{tr} + M_{timber} + L_{mort(BB)} + L_{HRroot}) - D_{DW} \quad \text{.....(13)}$$

A small amount (approximately 4 percent) of harvested timber is assumed to be left on site following harvest and this is used to estimate L_{tr}:

$$L_{tr} = L_{timber} \times RF \quad \text{.....(14)}$$

The deadwood input from natural mortality (M_{timber}) is derived from allometric equations applied to the DBH and H of dead trees after mortality iterations (see Appendix A & D), while $L_{mort(BB)}$ and L_{HRroot} are known from the analysis for the litter pool in the previous section above. The decomposition losses from the new input deadwood carbon pool (eq. 13), existing decaying logs (DL_{old}) and decaying stumps (DS_{old}) are calculated using equation 15 based on decomposition factors of 0.095 for stumps and 0.076 for roots (Tobin et al., 2007):

$$D_{DW} = 1 - \left[\sum [L_{tr}, M_{timber}, DL_{old}]^{-D_{\log} \times t} + \sum [L_{mort(BB)}, L_{HRroot}, DS_{old}]^{-D_{St} \times t}\right] \text{... ..... (15)}$$

The carbon stocks in the decaying existing deadwood pools DL_{old} and DS_{old} are input by the user, defined in section 4 lookup table). In the case of decaying logs

Soil Carbon Stock Change (*Project_soils table*)

In the current version of the software and the example lookup table, soils are classified into three major groups; mineral, peat and peaty/mineral soils. Peat soils are organic soils with a depth greater that 30 cm and peaty/mineral soils are a continuum between the peat and mineral categories. Current research information suggests that mineral soils in Ireland do not represent a source of carbon emissions, and therefore soil carbon stock changes are reported only for peats and peaty/mineral soils. The emission for peat soils given by equation 16 is based on published data from the UK (Hargreaves et al., 2003), as described for *Land Converted to Forest Land* in section 7.3.3 of this NIR, but information on soil classification and peat depth available from the NFI is also taken into account.

$$\Delta C_{So} = \sum_i \left(A_i \times EF_{soil}\right) \text{.....(16)}$$

The area (A_i) of the 0.05 ha plots with peat soils is multiplied by 20 to scale the measurement up to 1 ha. The EF_{soil} is 4 t C/ha.yr for the first four years following afforestation and is zero thereafter. Emissions from peaty/mineral soils are calculated in the same way (equation 17), but a soils depth function (SD) is applied to the emission factor to account for the smaller organic carbon pool available. If soil depth is less than 30 cm then,

$$\Delta C_{So} = \sum_j \left(A_j \times EF_{soil} \times SD\right) \text{ .....(17)}$$

and

$$SD = \frac{depth(cm)}{30cm} \quad \text{.....18)}$$

The soil depth is also defined by the user in the lookup tables

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